METAL PROGRESS

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A practical suggestion that may help you

SPEED your steel by sending open orders (not inquiries) to a dependable source of supply. We are glad to receive all inquiries and give them prompt personal attention but with today's emergency demands there is a chance that certain stocks may become depleted while the request for quotation is being handled.

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THE TUNGSTEN SITUATION

one solution

for toolsteel

By Joseph V. Emmons
Metallurgist
The Cleveland Twist Drill Co.
Cleveland, Ohio

IN THESE TIMES OF NATIONAL EFFORT to tune our industrial machinery for defense needs, no item is more important than cutting tools. War is mechanized and the arming of our new forces requires vast quantities of ships, airplanes, tanks, guns, automotive equipment and other ordnance material made of metal. The production of such implements of war requires cutting tools of the highest quality in quantities never before produced.

The majority of these cutting tools are made of high speed steel, containing about 18% of tungsten as its principal constituent, together with 4% of chromium and 1% of vanadium — the variety commonly known as "18-4-1". Smaller quantities of high speed steels containing 14% tungsten are used. Several types of toolsteel having still lower percentages of tungsten are used in limited amount; for example, some hot die steels contain 8 to 15% tungsten, fast finishing steels contain about 4% tungsten, hacksaw steels about 1% tungsten.

Additional uses of tungsten in alloy steels and for other purposes have been enumerated by the Editor in the section on tungsten of an article on strategic metals in the February issue of METAL PROGRESS. These include stellite for cutting tools and hard facing, tungsten carbide cutting tools and hard alloys, austenitic valve steels and valve seats, armor piercing projectiles, erosion resisting gun liners and magnet steels. In the form of the pure metal, tungsten is also used for lamp filaments, X-ray targets, and electrical contact points. It is, however, estimated that a high percentage of the tungsten consumed in the United States in normal times (perhaps 70%) is used in high speed steels for cutting tools.

The tungsten available in the world's markets is limited at all times, the largest supplies coming from China and Burma. The United States produces part of its requirements. Figures on tungsten in the table (page 428) are from the Minerals Yearbook of the Bureau of Mines for 1939, with the data for the years 1939 and 1940 added from authoritative sources. It will be observed that for the last four years of record (1936 to 1939 inclusive) the apparent consumption of tungsten metal totaled 23,800,000 lb., of which 12,794,000 lb. or 54% was shipped from domestic mines, while 11,110,000 lb. or 46% was imported.

A glance at the figures indicates a wide fluctuation in demand for tungsten. Our present interest is in some yardstick wherewith we can measure the expected requirements in the strenuous months ahead. It is thought that the figures for steel production will be such a measure — at least of the requirements for high speed steel, since its principal use is for machining steel; likewise steel production is an accepted index of general industrial activity. For this reason the statistics of steel production have been added to Table I, and the ratio

Table I — Statistics on Tungsten and Steel Consumption

Year	Figures for Tungsten (1 = 1000 Lb. of Metal)				Steel Ingots (d)	Lb. Tungsten Per Ton Steel
	Shipments	Imports (a)	Exports (a)	Apparent Consumption		
1910	1,733	1,941	89	3,585	28,172	0.127
1911	1,084	446	(b)	1,530	25,792	0.059
1912	1,266	1,542	(b)	2,808	33,919	0.083
1913	1,463	2,047	(b)	3,510	33,914	0.104
1914	942	775	(b)	1,717	25,558	0.067
1915	2,219	1,848	(b)	4,067	35,038	0.116
1916	5,637	4,304	615	9,326	46,370	0.201
1917	5,847	5,054	2,489	8,412	48,854	0.172
1918	4,817	12,233	1,319	15,731	48,217	0.326
1919	311	10,388	41	10,658	37,738	0.282
1920	206	4,203	5	4,404	45,787	0.096
1921	....	2,257	....	2,257	21,531	0.105
1922	....	2,908	1	2,907	38,717	0.075
1923	229	79	4	304	48,704	0.006
1924	538	142	3	677	41,228	0.016
1925	1,133	1,694	10	2,817	49,438	0.057
1926	1,315	2,884	24	4,175	52,569	0.079
1927	1,108	2,198	16	3,290	49,030	0.067
1928	1,150	2,969	13	4,106	56,364	0.073
1929	790	6,446	82	7,154	61,432	0.117
1930	668	3,998	24	4,642	44,347	0.105
1931	1,336	189	846	679	28,480	0.024
1932	377	106	113	370	15,080	0.025
1933	852	379	683	548	25,642	0.021
1934	1,950	954	563	2,341	29,062	0.081
1935	2,279	892	798	2,373	38,013	0.062
1936	2,486	3,767	104 (c)	6,149	53,214	0.115
1937	3,331	5,696	(b)	9,027	56,356	0.160
1938	2,897	162	(b)	3,059	31,596	0.097
1939	4,080	1,485	(b)	5,565	52,537	0.106
1940	....	....	....	10,000 (a)	66,674	0.150

(a) Partly estimated. (b) Figures not available. (c) Complete data not available.
(d) In thousands of net tons; from Gano Dunn's report to the President, Feb. 22, 1941.

figured, year by year, of tungsten to steel. The first chart shows graphically these statistics.

It seems that there is a fairly close relationship between the steel production and apparent consumption of tungsten. A severe dislocation of this relationship is, however, noted in the war years culminating in 1918 and in the following depression years. This is more in evidence in the second chart, showing the pounds of tungsten apparently consumed per ton of steel produced.

It appears from this chart that tungsten is used in greater proportion during boom times and in lower proportion during depression times. The average consumption of tungsten per ton of steel produced for the last five years of record (1936 to 1940 incl.) was approximately 0.13 lb. If this ratio under normal conditions be applied to the near-capacity production of 87,500,000 tons possible for 1941,* it appears that approximately 11,375,000 lb. of tungsten metal would be required for peace-time uses. It is recognized, however, that this "normal" ratio will probably be exceeded during the present defense program. It certainly was in 1918.

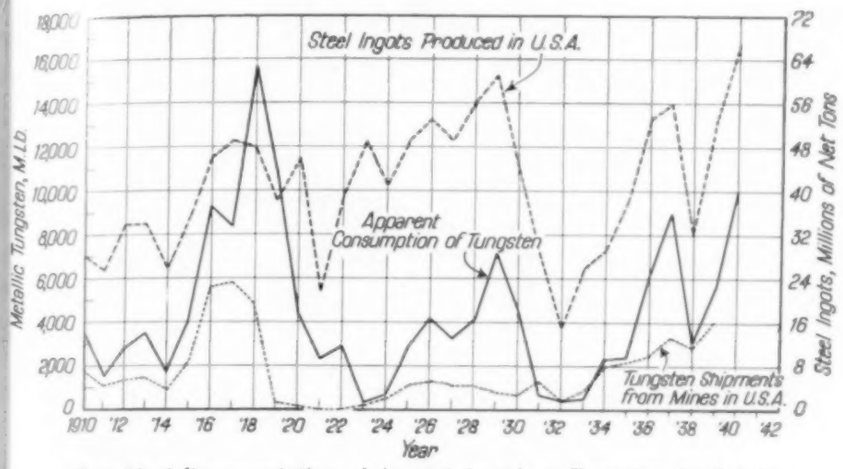
At present the demand for tungsten from our defense industries is rapidly increasing while receipts from abroad are uncertain. A tungsten shortage of serious proportions has already developed, despite the U. S. Government's effort to build a stock pile dating as far back as October, 1939. Toolsteel manufacturers have been urged by Mr. Knudsen's Office of Production Management to give every consideration to the use of substitutes for tungsten wherever possible and to emphasize the desirability of such substitutes to their customers.

A similar situation developed in 1917 and 1918 at which time there was such an acute shortage of tungsten that the price of high speed steel went to $3 a pound, with an insufficient supply available even at that price. Fortunately many factors have operated to change the picture materially from the one of 1918. First, on the favorable side: The peace-time production of tungsten in this country has increased; second, the development of an immense supply of molybdenum in this country gives us a substitute which, for use in high speed steel, appears in proper combination to be actually superior to tungsten; third, the discovery of the sintered tungsten carbide type of hard metal alloys has made small amounts of tungsten go a long ways in cutting tools for some purposes.

On the other hand, the greatly increased number of high powered modern machine tools in use has increased the demand for high speed steel tools to more than offset the increased amount of tungsten produced in this country.

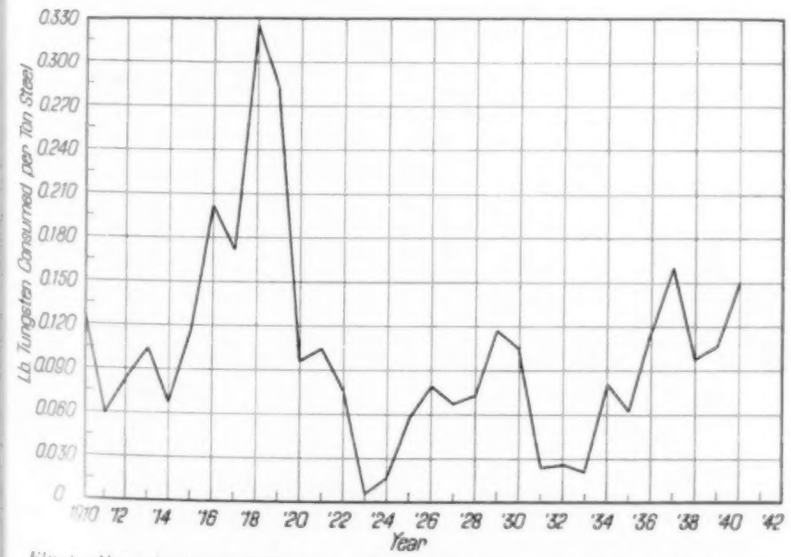
*This estimated "maximum reliable steel making capacity" of the steel industry is in Gano Dunn's report to President Roosevelt, Feb. 20, 1941, page 42.

It is estimated that in 1918, less than 25% of the cutting tools in use were made of high speed steel, while today the figure is more than 75%. It therefore appears probable that our present defense program will require quantities of high speed steel far in excess of previous experience.


Steel Ingots Produced in U.S.A.
Apparent Consumption of Tungsten
Tungsten Shipments from Mines in U.S.A.
Metallic Tungsten, M.T.U.
Steel Ingots, Millions of Net Tons
Year

Graphical Representation of Annual American Tungsten Production, Tungsten Consumption and Steel Ingot Production, 1910 to 1940 Incl.

It now appears that in spite of the steadily rising price of tungsten ore, encouraging increased domestic production, and the continuation of moderate receipts of tungsten ore from China, the supply of available tungsten is inadequate for our present needs, with our defense program only beginning! We should now consider, in view of this situation, what can be done about it. In this connection a little historical data may be interesting.



Fluctuations in Annual Tungsten Demand in U. S. A., 1910 to 1940 Incl., as Measured by the Ratio of Tungsten Consumed to Steel Production

Molybdenum for Tungsten

As a result of the tungsten shortage and consequent inadequate supply of high speed steel in 1918, at least three groups of people in the United States, who had been hard hit by the tungsten shortage and its attendant difficulties, were moved to do something about it. These were the Watertown Arsenal group, headed by Captain (now Lt. Col.) S. B. Ritchie, the Universal-Cyclops Steel Corp. group headed by Frank Garratt, and the Cleveland Twist Drill Co., whose metallurgical department is in charge of the writer. All three groups worked independently and for a long time without knowledge of the activity of the others. All three made substantial contributions to our fundamental knowledge of the high speed steels in which molybdenum is used as the principal alloying element.

Molybdenum high speed steels had been known for many years but, at the beginning of these researches, they were considered to be unsatisfactory and were not being made commercially. Frank Garratt and the writer arrived at similar solutions of the problem, namely, that the addition of small amounts of tungsten to molybdenum high speed steel controlled the grain growth and improved the cutting performance until tools made from it were equal to or better than tools made from 18-4-1. All three groups of experimenters early arrived at molybdenum high speed steels almost as good as 18-4-1. Not until the discovery of the beneficial effects of small additions of tungsten was it made better than 18-4-1.

The original purpose of this research in the Cleveland Twist Drill Co. was to free ourselves, and the country in general, from the threat of another perhaps even more severe shortage of tungsten for high speed steel.

The result was the development of the molybdenum-tungsten high speed steel now known under the general trade name of "Mo-Max". In this type of high speed steel the principal alloying element is molybdenum, of which the United States has a plentiful supply. Tungsten is used only in minor quantities for its powerful auxiliary effect. The amount of tungsten required, even if all of our high speed steel were of this type, is well within the quantity available from mines in the United States, for a ton of tungsten metal will make 12 times as much Mo-Max high speed steel as it would make if used in conventional 18-4-1.

The commercial introduction of this radically new type of high speed steel was begun eight or nine years ago to compete with the then standard 18-4-1 type. The high cutting quality, the uniformity and the stable and moderate price have proved such an irresistible combination that, in spite of great inertia and considerable competitive opposition, its use has steadily increased to where it probably comprises more than 20% of the high speed steel used in the United States. Only after its improved quality and commercial workability had been successfully demonstrated and gained substantial headway did other competing types of molybdenum high speed steels appear on the market.

During the commercialization of the general purpose molybdenum-tungsten type of high speed steel, the need was felt for special purpose variations to compete with some of the many variations of the high tungsten steels already established. In response to these demands, there have been developed a number of special types which constitute what may be called the "Mo-Max Family of Molybdenum-Tungsten High Speed Steels". For convenience in consideration, the various members of this family may be classified and described in comparison with the previously used types. (The approximate compositions of the principal members of this family are shown in Table II, together with type analyses of comparable high tungsten steels.)

Type 1 is the general purpose high speed steel available in a wide range of carbon contents for different purposes. It is so well established in the plants of hundreds of consumers that detailed description seems unnecessary. Sufficient to say that during the past eight or nine years many thousands of tons of steel have been made and more than a hundred million tools have been sold by many tool manufacturers. These high speed tools have been entirely acceptable to the most discriminating trade. It should be observed that this type has a particularly low percentage of other strategic and critical raw materials (low vanadium, low chromium and no cobalt) and so requires a minimum of the imported alloying elements that should be economically used. It should be noted that Type 1 is probably the most easily machinable of all high speed steels. Increased vanadium and the addition of cobalt both act to decrease the machinability of high speed steels, especially in grinding.

Type 2 is in the high carbon, high vanadium class, which is particularly useful where great hardness and resistance to abrasion are required. It is suitable for such tools as reamers and broaches and for cutting abrasive materials.

Type 3 is a hot die steel, for the most severe hot coining, pressing, extruding and similar operations.

Types 4, 5, 6 and 7 are all cobalt high speed steels, suitable for all purposes where such steels have earned themselves a place in industry. These four types cover, in a general way, the existing cobalt high speed steel field. The higher cobalt contents are for the most severe duty. The higher vanadium contents are for maxi-

Table II — Analyses of Comparative Types of High Speed Steels

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
	Molybdenum-Tungsten High Speed Steels (Mo-Max)						
Carbon	0.80 *(a)*	1.00	0.40	0.80	0.85	0.88	0.88
Molybdenum	8.75	8.75	5.75	8.75	6.50	9.50	8.25
Tungsten	1.50	1.50	1.00	1.50	1.50	1.50	1.50
Chromium	3.75	3.75	3.50	3.75	3.75	3.75	3.75
Vanadium	1.00	2.00	0.75	1.00	2.00	1.00	2.00
Cobalt				5.00	5.00	8.00	8.00
	Comparable Types of High Tungsten Steels						
Carbon	0.70 *(a)*	0.82	0.35	0.70	0.70	0.75	0.82
Tungsten	18.00	18.50	14.00	18.00	14.00	18.00	18.50
Molybdenum		0.70					0.70
Chromium	4.00	4.00	3.00	4.00	4.00	4.00	4.00
Vanadium	1.00	2.00	0.50	1.00	2.00	1.00	2.00
Cobalt				5.00	5.00	8.00	8.00

(a) Varies over a considerable range for various purposes.

mum abrasion resistance. Especial attention is called to Type 6, which has been found particularly suitable for machining very hard steel such as armor plate. All four cobalt types have been made in substantial quantities for several years and are well established in industry wherever their higher cost is justified.

Heat Treatment

The heat treatment of the Mo-Max types is carried on at forging temperatures around 1900° F. and hardening temperatures around 2200° F., both substantially lower than used for 18-4-1.

Table III — Other Molybdenum High Speed Steels

	Type A	Type B	Type C	Type D	Type E	Type F
Carbon	0.85	0.80	0.80	1.25	0.70	0.85
Molybdenum	7.50	9.00	4.00	7.50	8.00	6.00
Tungsten			5.00			6.00
Chromium	4.00	4.50	4.00	4.50	5.00	4.00
Vanadium	2.20	2.20	1.60	3.75	1.25	1.75
Cobalt					3.00	
Boron					0.15	

These lower temperatures reduce the costs of heating by longer furnace life and lower fuel costs. The working conditions are also improved by the substantial reduction in operating temperature. Tempering temperatures are similar to those used for 18% tungsten steels — that is, about 1050° F.

The molybdenum high speed steels are known to decarburize slightly more readily than 18-4-1 when exposed to oxidation during heating. The amount of this decarburization has been greatly exaggerated in the minds of people not thoroughly familiar with the phenomenon. A number of commercial methods are now available for controlling this tendency; in fact the best available methods are none too good for *any* high speed steel.

In recent years, several additional types of molybdenum high speed steels have been introduced commercially by various steel manufacturers to compete with the original molybdenum-tungsten types. Some principal ones are illustrated in Table III.

Such a substantial number of consumers of high speed steel have already standardized on Mo-Max, either completely or in part, that it has already provided considerable relief from the tungsten shortage. It has also had a definite stabilizing effect upon the tungsten and the high speed steel markets. Now under the stress of the urgent necessity for national defense, it offers the best and most desirable solution of the problem of providing an adequate supply of high speed cutting tools. It will do this without the necessity for increased expenditure, for the steels are marketed at a substantial saving over the cost of 18-4-1.

It has been estimated by L. Gerald Firth in *Steel*, March 17, 1941, page 24, that the present demand for high speed steel is at the rate of 20,000 tons annually. If this were all to be 18% tungsten steel, then 7,200,000 lb. of tungsten would be required for high speed steel alone (figuring 100% recovery in the steel furnaces). If, on the other hand, this 20,000 tons of high speed steel were all Mo-Max, only 600,000 lb. of tungsten would be required. This would release approximately 6,600,000 lb. of tungsten for other uses.

Thirteen of the principal manufacturers of high speed steel in the United States are manufacturing this truly strategic alloy under their own brand names as follows:

Company	Brand Name
Allegheny Ludlum Steel Corp. Pittsburgh, Pa.	"LMW"
Bethlehem Steel Company Bethlehem, Pa.	"Bethlehem HM"
Braeburn Alloy Steel Corp. Braeburn, Pa.	"Mo-Cut"
Carpenter Steel Company Reading, Pa.	"Star Max"
Columbia Tool Steel Company Chicago Heights, Ill.	"Molite MT"
Crucible Steel Co. of America New York, N. Y.	"Rex T-Mo"
Henry Disston & Sons, Inc. Philadelphia, Pa.	"Di-Mol"
Halcomb Steel Company Syracuse, N. Y.	"Rex T-Mo"
Jessop Steel Company Washington, Pa.	"Mogul"
Latrobe Electric Steel Company Latrobe, Pa.	"Tatmo"
Simonds Saw & Steel Co. Lockport, N. Y.	"S.T.M."
Universal-Cyclops Steel Corp. Bridgeville, Pa.	"Mo-Tung"
Vulcan Crucible Steel Company Aliquippa, Pa.	"Vul-Mo"

It is evident from this list that Mo-Max is now in full production on a scale comparable to 18-4-1. All who are handicapped in any way by a shortage, or threat of shortage, of 18% tungsten high speed steel can shift to molybdenum-tungsten with full confidence of many available sources of supply.

CENTRIFUGAL CASTING

with axis vertical

By Nathan Janco
Consulting Engineer
Tulsa, Oklahoma

CONSIDERABLE ADVANCES HAVE BEEN made in the art of centrifugal casting during the past ten years. However, the immensity of the field of application of centrifugal casting has only been scratched. The fact that many different sizes and configurations of castings can be centrifugally cast has not been generally known.

When the subject of centrifugal casting is mentioned, the average engineer ordinarily thinks of cast iron pipe. The next thought is of iron liners and of various cylindrical castings usually of a high alloy or non-ferrous metal. In general, he thinks of centrifugal castings as being made on horizontal centrifugal casting machines, since this process has been in use for years with marked success.

Until recently, the use of centrifugal casting machines with axis vertical (or at any inclination to the horizontal) has been neglected. This neglect has been unwarranted, as the field of application for vertical centrifugal casting is much broader than that for horizontal casting. The Editor of METAL PROGRESS commented on this is his "Critical Points" last May, in giving the principal details of machinery and casting practice for propeller blade bushings cast of aluminum bronze.

The horizontal machine is best applied to castings of greater length than the diameter and which have a cylindrical bore. The yield approximates 100% (that is, there is no waste in runners or risers), but of the general run of castings very few have the proper shape for this type of machine. On the other hand, practically any size and shape of casting may be poured in a vertical casting machine. This is a rather broad statement, but is true technically; however, certain size castings and those having unhandy configurations are not economically poured in vertical machines at the present time.

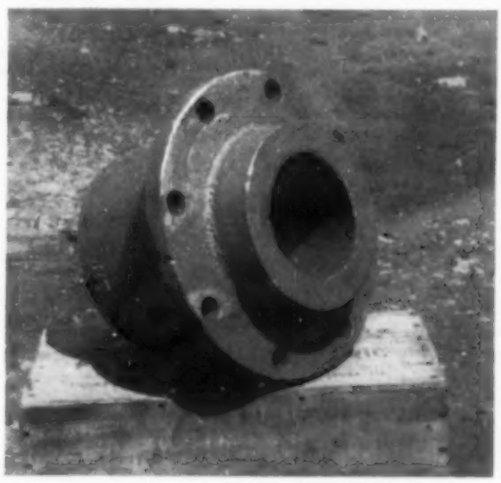
The question will immediately arise: "Why pour castings in a machine when they may be successfully cast statically?" The primary reasons are *(a)* to obtain better quality castings, *(b)* to produce castings more economically and *(c)* to cast a part which cannot be satisfactorily cast statically. These reasons do not necessarily go hand in hand as certain castings are centrifugally cast to increase the yield or to decrease cleaning room expense without having any idea of affecting the quality. Usually, however, some improvement in quality results.

Steel castings statically poured with a yield of 40 to 55% may be centrifugally cast with a yield of 65 to 85%. Instead of using the force of gravity through the liquid metal in the heads to obtain sound castings, use is made of centrifugal force. Thus, heads are seldom required (but if necessary in rare instances, much smaller heads are used). Cleaning room costs are therefore considerably reduced. Denser castings result with physical properties comparable with those of forgings. This fact is

demonstrable, but is reserved for later consideration in an article on metallurgy; at this place it is primarily desired to call attention to the wide field of casting open to foundrymen who use the vertical machine.

Centrifugal castings are pressure castings, akin to forgings. When a piece of steel is forged, it is heated to a temperature at which the metal is relatively soft and pliable and pressure is then exerted upon the metal while it is in the *plastic* state. A large proportion of the forging work is done to move the plastic metal about to give a proper external shape. In centrifugal casting, pressure is exerted upon the metal while it is in the *molten* state, requiring less force to obtain a similar effect — namely a proper shape and sound structure. Moreover, no flow lines exist, as in a forging. The centrifugal casting has equal toughness in all directions, which is not true of a forging.

A True Centrifugal Casting Weighing 9 Lb. in Which the Central Hole Is Formed by Centrifugal Force. The method requires a nice adjustment of the amount of molten metal poured, else the axial hole is too large for use, or so small it requires an excessive amount of machining

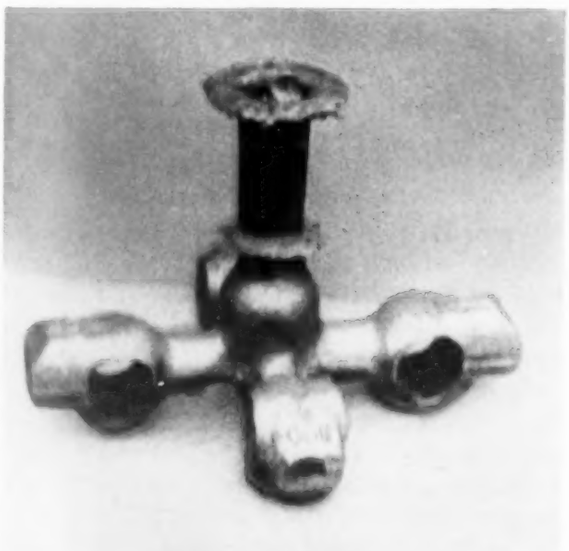


A 95-Lb. Steel Casting Made in a Centrifugal Mold Containing a Central Core. This method may be called "semi-centrifugal casting"

Another advantage is that the percentage of rejected castings is reduced. Bad castings come from human errors and are no more prevalent in centrifugal casting than in static casting. Moreover, centrifugal force assists in counteracting some human errors which otherwise would result in a bad casting. There is greater leeway in the foundryman's efforts to obtain good sound steel castings and at the same time do the job much more economically.

Let us consider the various methods which can be used in vertical centrifugal casting. *Three* methods will be described, whose products are nominally called "centrifugal castings". Actually, only one of the products is a true centrifugal casting.

Method I, or True Centrifugal Casting: In this method, the casting is rotated about its own axis during solidification. The casting may have a cylindrical hole through its center or may be solid. In the latter case the metal of the solid center will be inferior in quality to that at the periphery. In any event, no central core is used. The metal solidifies from the outside toward the center, which results in the highest quality of metal at the surface. Yields approaching 100% may be obtained — that is, there are no sprues, gates, risers or sink heads to remove and remelt. Typical castings of this type are small gear blanks, gears, cutters, bushings and liners. Frequently, of course, the cen-



"Pressure Casting" by Placing Mold Cavities Toward the Outside of the Spinning Flask. Valve plugs, two each of two types, weight 4 and 4.5 lb. respectively, centrifugal cast in dry sand. Yield is 74% as compared with 26% for conventional foundry practice requiring high large sink heads to insure dense, leak-proof metal

tral region is open, and finished by machine shop operations.

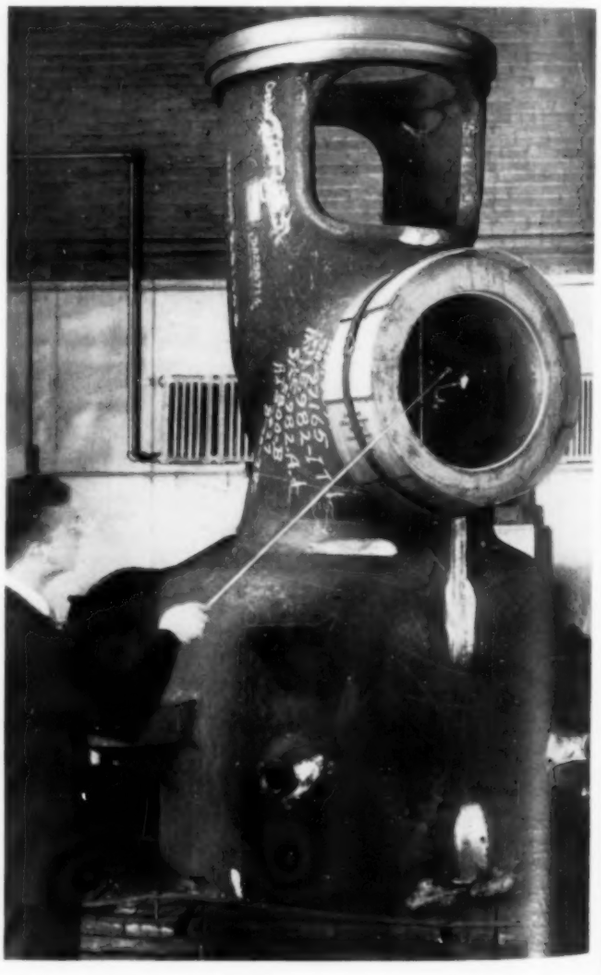
METHOD II, or Semi-Centrifugal Casting: This is very similar to Method I but, due to the irregular contour of the central bore, a core is used. (A revealing sketch of such molds used by Ford Motor Co. may be found in METAL PROGRESS, May 1940, page 526.) As cooling takes place from the periphery toward the center and from the center toward the periphery due to the center core, the quality is similar to a static casting made with extremely tall heads. Gates of various types may be used, some of which serve the function of a head, some merely for a pouring basin. Hydraulic heads of over 100 equivalent feet of molten metal are possible by centrifugal force! METHOD II is adaptable to a wide variety of castings such as jaw clutches, sheaves, gear blanks, casing heads and flanges.

METHOD III, or Pressure Casting: This refers to the use of centrifugal action generating a high pressure to force the molten metal into the mold (rather than to the use of the resulting casting to resist high pressure). This method is used for unsymmetrical castings which cannot be spun about their own axes. As shown in the third halftone on page 433, the mold is arranged so metal is poured into a gate or cavity placed at the center of rotation. Molds for the castings are arranged symmetrically about the center of rotation with gates leading to each from this central down gate. The resulting casting looks like a shaft with spokes extending therefrom, having individual castings at the ends of the spokes. METHOD III requires a high degree of technique and experience to design properly the gating and spacing of the individual castings about the periphery. Usually, only small castings are pressure cast, such as unions, valve bodies, gates and plugs, and intricate castings which otherwise would yield large quantities of sprue scrap.

It therefore appears that the term "centrifugal casting" is no longer adequate; more specific terms should be used. There is first the true centrifugal casting which is spun about its own axis, has no central core, and in which the cooling takes place from the periphery toward the central axis. Second is the semi-centrifugal casting which is spun about its own axis but does have a centrally located core; in this variety solidification proceeds from the central axis toward the periphery as well as from the periphery toward the axis. Third is the method of pressure casting in which the castings are arranged symmetrically about the center of rotation; normal type of cooling takes place in these as in a static casting.

Any metal which can be cast statically may be centrifugally cast as well. Metals which have a relatively large amount of shrinkage upon solidifying and cooling, such as steel, show the greatest savings economically. Very few advances in the casting of metals have been made in the last hundred years. Foundry work is still too much of an art, and the trend certainly is to put foundry work on a scientific basis. Better metal, denser castings and decreased costs are daily being striven for. Centrifugal casting is a step along the path we are seeking. It may even be the answer.

Inspector Places Capsule Containing Radium Sulphate at Center of Outlet in Naval Turbine Casting. Films have been strapped around 3-in. flange, and gamma rays from the radium will make a shadowgraph that will record any interior porosity at this important region. (Westinghouse Electric & Mfg. Co., Lester, Pa., Steam Division)



CRITICAL POINTS

by the editor

REVISITING RUSTLESS IRON & STEEL Corp. and find the plant enlarged almost beyond recognition in 18 months. Two new electric furnaces provide a 75,000-ton annual ingot capacity in all, exclusively rustless chromium steels, one of the largest outputs of any plant in the world. EDWARD GEARY, assistant vice-president, was busy with problems arising from the rationing of nickel. Nickel is in fact subject to priority and unfortunately now obtainable only for defense orders, when accompanied by proof in the form of Government job or contract numbers. While it is ordinarily difficult to get permission to substitute one material for another in official specifications, it is worth a try when 18-8 stainless is satisfactory and pure nickel or high nickel alloys have been ordered. Likewise the straight chromium steels have enormous potentialities, and can doubtless be used in many places where 18-8 is now stylish. A whole family of 12 to 14% Cr steels (improved for special applications by either aluminum, tungsten or molybdenum), as well as the 16% Cr, 1½% Ni alloy, is now commercial and backed by a growing number of applications. .....Was impressed by the large battery of swing grinders, working over the entire surface of ingots and billets; cost of the grinding wheels alone passes belief. *Surface* of stainless steel articles is everything — a trite saying, but nevertheless re-emphasized in every operation in Rustless's mill, devoted to bars, rod and wire. Here the techniques of electrolytic polishing and bright annealing were commercially applied (and first seen by this observer). STANLEY WATKINS, manager of development, pointed out a new method of loosening difficult scale on hot-rolled or forged material. The chromium oxides that are formed at high temperatures are notoriously hard to cut by acid, so the scaled metal is hung for a few minutes in a large tank of molten caustic (at about 750° F.) and made cathodic by an electric current of about 25 amp. per sq.ft. Sodium plates out on the metal, tends to reduce the oxides without attacking the metal underneath.....Up and out into a water quench the steel is fairly clean, and in such shape that the subsequent dip in nitric-hydrofluoric acid solution cleans the surface perfectly and promptly.

Rustless's Output Expanded

Breaking Scale by Molten Caustic

OUT to Baldwin Locomotive Works, sprawling in 12 huge buildings over 520 acres at Eddystone, south of Philadelphia, and found it a strongly guarded arsenal making gun mounts and tanks. Once busy and turning out ten locomotives a day, during the 1930-depression the plant was all but shut down. A spark of life glowed in the shop housing the Southwark division, where hydraulic equipment and testing machines were being made. FRANCIS TATNALL, sales manager for testing machines, explained "volume production" methods designed to deliver one tension-compression machine every day, precise enough for research work into physical properties and rugged enough for all-too-frequent use as a hydraulic press. All the forgings and castings are made and machining done in shops able to build presses up to 20,000,000-lb. capacity, and so the production of the loading and load carrying devices for testing machines is an economical adjunct of another important line of endeavor. (Whether the testing machine business is the tail and the hydraulic press business the dog depends on the proportion of orders going through.) A considerable degree of standardization also makes for economy; for instance, all machines below

Tension Testing Machines and Hydraulic Presses From One Shop

60,000-lb. capacity look alike for they use the same patterns, a matter which enables the shop to produce parts by the dozen rather than one at a time. The load-measuring device is the well-known "Emery capsule", in itself essentially a hydraulic ram of infinitesimal movement, and which serves as cylinder head for the hydraulic load-producing cylinder. This capsule is made and calibrated in an appropriate range of sizes by the A. H. Emery Co. in Stamford, Conn. (legatees of the builders of the famous old Watertown Arsenal testing machine, still among the best in size and precision after 60 years). Capsules, indicating dials, motors, hydraulic pumps and control valves, instrument panels and automatic recorders are therefore merely items on the assembly line at the Southwark plant. TATNALL makes much of the response and ruggedness of his testing equipment, and proves his point by telling how one of the largest sizes has been readily adapted into a huge, high speed, precision metal working press for the study of forging and extrusion processes.....Visited, hurriedly, PAUL IRWIN, engineer of tests for Baldwin Locomotive Works and subsidiaries in Eddystone. The ancient laboratory is being rapidly modernized, in keeping with the type of work now current. Instead of spending most of the effort on seeing to it that staybolts for XY Ry. conform to the XY's physical specifications, IRWIN is using the modern techniques of X-rays, photo-elasticity, strain-gage rosettes, and brittle coatings which show Lüders lines, in his study of movements in riveted boiler seams, stresses and strains in cast steel locomotive driving wheels, deflections in welded underframes of diesel locomotives, and internal conditions in cast and welded gun-mount parts.

Modernized Materials Laboratory

EXERCISED a yearning for fast, safe and comfortable travel (on the ground) by riding from Philadelphia to New York on the Reading Railroad's "Crusader" — "sheathed in gleaming armor of stainless steel", to quote the lyrical advertising agent. (A photograph of this Budd-built train was used on our cover for September 1939.) Luxurious yet functional in every respect, this train is hauled by steam, 80 miles in 80 min., through some of the densest railroad traffic in the world. Strange more people do not prefer such a conveyance, or the Baltimore & Ohio's "Royal Blue", with a ferry ride across the Hudson in full view of the magic New York skyline, to a cattle train that ducks them headlong under the river and dumps them out in the cellar of an imitation Roman bath house.... Saw again the top of the American Radiator Co.'s building, near the Public Library, and noted that the gold leaf placed on its pinnacles 20 years ago is still gleaming, naturally untarnished, but remarkably unsooted and yellow.....On the contrary, took some soap and water and tried to wash the dirt off a stainless steel pilaster outside JOHN MAPES' windows in the Empire State Building. (He graduated long ago from METAL PROGRESS to *Steel Facts*, publication of the American Iron & Steel Institute.) Some powdery dirt came off easily, and the surface underneath was smooth as glass, but its color is no longer steel blue but dirty gray. The reflection from stainless steel decorations, unwashed after years of exposure to smog, is like white sunlight from black glass. .....Together, JOHN and I, we went up to the Airlines Terminal, newly built across 42nd St. from Grand Central. Over the portal is a huge map of the world — colored stainless steel, much praised by the builders. To me, it is violence to cover stainless steel with any material, sure to be far less durable, and therefore the stark, clean escalator, gleaming bare steel, is far more beautiful.....Took another look at the cast stainless plaque over one of the entrances in Rockefeller Center, and it looks better the second time. (Some night it may be properly illuminated.) The lobby wall of the Time-Life building — in the same architectural marvel — supports some wooden sculptures by MILLES, so waited around until his silly little metal bird flapped his wings and cuckooed out the hour, to the accompaniment of horrid grinding of gears. They had rather picked up some parts from a Model T! .....Also went out to the Cloisters and saw some old stone gargoyles.

Effect of Smog on Exposed Metal Trim

Decorations of Stainless

Comparative grading from low to high: Wood, stainless, stone — and if that be treason to metallurgy, make the most of it.

TO THE EDITOR'S desk come several plaints from several directions about the drafting of technical men into the national army, causing dislocations in defense industry difficult to remedy. This unfortunate situation is likely to

get worse before it gets better, what with the increasing enrollment of draftees, unless supervisors and employers bestir themselves..... There is the greatest diversity of practice by the local draft boards. Some overlook the fact that the Selective Service Act gives priority to the production of material supplies over the training of man power in the national army. On the other side, many young men mistakenly assume that it verges on the unpatriotic to ask deferment on account of occupation.....When asking for deferment, a better case can ordinarily be made for metallurgists in production jobs than for men in the research laboratories. (Strange hypothesis, that experimental work is of no great value to preparedness!) It would therefore be desirable for executives to survey their staffs *now*, seriously study the type of work done by each man of draft age, and get an agreement among the responsible officials in the plant as to which men should properly be deferred as necessary men to munitions production. These potential draftees should then be informed of the facts and instructed to retain their questionnaires, when received, until necessary affidavits can be attached. These affidavits as to nature of occupation should be signed by as high an official in the company as possible, since draft boards frequently hold that departmental supervisors or personnel managers ask for deferment of their men principally to avoid the trouble of replacing them. Such questions as the following should be clearly and vigorously answered:

Deferment of Draftees Necessary for Production

What is the nature of the occupation of the registrant?

How does it contribute to the self-preservation of this nation, directly or indirectly?

Is it an occupation or skill difficult to learn, and one in which there is now, or soon will be, an actual and serious shortage?

What will be the effect upon this activity if this individual is taken for military training and service?

Has the necessity for speeding up in rearmament been given sufficient consideration?

The President has said that the United States must become the great "Arsenal of Democracy". How is this registrant in his present job contributing to the accomplishment of this object?

If the local board refuses an occupational deferment to such a man, carefully selected by executives in his company, the draftee should then be urged to appeal to the State Board, in the manner directed by law, and be given every proper assistance in this appeal. The basis of the appeal must be that the local board has not correctly weighed all the pertinent facts.

On hearing from someone that neither the Shepherd nor the Swedish fracture standards are now available, inquired of Ben Shepherd, past president ASM, what the true situation is, and he writes that sets will again be available soon. Manufacture is not a very easy task. Originally it was decided that the bars must be large enough to give a good area for comparisons, say a ¾-in. round. Also that the fracture must be uniform all over (it's easy in a ¼-in. round; a ¾-in. round is something else). Lastly, the break has to be square, to avoid light and shadow effects. Even though a definite manufacturing procedure is followed, the result is not entirely predictable, yet the grain size must not vary from correct in the slightest degree.....The origin of the matter is interesting. Shepherd was long concerned with "body" or "personality" of toolsteel, and had been using a group of homemade fracture specimens as references in grading his firm's purchases. When visiting in Sweden early in 1930 he acquired a set of 20-mm. square bars, said to be "Jernkontoret standards"; most of these had a case and core and the fracture standard referred to the case. Later he compared them with another set from another steel company and found they did not correspond, so he accepted the challenge to do a better job. To quote Shepherd's letter: "We forgot the Swedish intervals and made set after set, separating adjacent fractures a little here, pulling others closer together there. This graduation was entirely by eye; the only criterion was something similar to that in a musician's ear which hears a note slightly sharp or flat. The fractures were moved until they all appeared in harmony. How well this was done was proved by Edgar Bain, who obtained from me a great many broken and graded fractures, and measured their grain size metallographically. The grain diameter when plotted against A.S.T.M. grain size gave a straight line—quite a compliment to the accuracy of our original work. Another compliment (or coincidence?) is that an entirely different type of Swedish fracture standards has now come into being. They are small pieces in a series which checks the Shepherd samples exactly!"

Origin of the Fracture Standard

FLAME HARDENING

cast iron

bearing rings

By James L. Foster
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Austin-Western Road Machinery Co.
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WITH THE ADVENT OF FLAME HARDENing by the oxy-acetylene torch, rapid advances have been made in the surface hardening of cast iron and steel whereby a hardened surface is produced without distortion and at the same time the desirable properties of the soft core are retained with its high shock resistance and ductility.

Cast iron with suitable chemistry to permit such a procedure must be used. The general type found suitable in our practice is as follows:

Graphitic carbon	2.00 to 2.50%
Combined carbon	0.50 to 0.80%
Manganese	0.70 to 0.90%
Silicon	1.50% max.

Molybdenum or chromium may also be added as alloys. Molybdenum in quantities between 0.25 and 1.25% retards the transformations in both the liquid and solid state. This in itself limits volume changes, and thus permits smaller tolerances on machined parts which must be finish ground. Some investigators believe that molybdenum has a tendency to cause the graphite flakes to take on a somewhat nodular form, and thus produce an iron of improved physical properties.

With combined carbon in the above range (0.50 to 0.80), it is also possible to produce a hardened structure containing considerable cementite, acquired by solution and combination of some of the graphite.

Hardness Pattern in Cast Iron Rings

In order to show how we are using the above principles, let me describe the bearing rings which we cast out of the above analysis in orders of several hundred at a time. For this purpose we add 0.25% molybdenum to the basic analysis quoted.

The large halftone shows two types of rings machined ready for hardening. The left-hand ring is a thrust ring, placed on the outside of two roller bearings. Its near face and inner edge must be hardened against wear. It is about 11½ in. in outside diameter and is 1 in. square in cross-section. The right-hand ring has the same outside diameter and flange width; in cross-section it has a channel shape and is 2¼ in. from face to face. It is used as a center ring between two roller bearings, is not machined inside, but is hardened on both faces. Grinding tolerance after hardening is 0.010 in.

We also can commend the hardening fixture we built. It consists of a radiagraph (automatic flame cutting machine) which runs around the annular steel table-top in a circle, directed by a radius rod from a central pivot. A flame harden-

Cast Iron Rings, 11½ In. Outside Diameter, Machined Ready for Flame Hardening of Faces

ing torch replaces the cutting torch in this radiagraph, and the heating flame (oxy-acetylene) is followed by a pipe carrying water for quenching, ¼ in. behind. The cast iron ring to be hardened is placed horizontally on a centered fixture below the table top, and a simply arranged canvas apron collects the splash of quenching water to be drained away from a pan below.

The speed of travel of the torch is governed by the small speed-control wheel on the cutting machine. This speed is determined by the depth of hardness penetration desired on the piece. In the case of these rings the inner diameter is 9¾ in. and approximately 4 min. are consumed in making the round trip.

Macros on page 438 show full size the hardness pattern obtained on the two types of rings. In each case the depth of hardening is ⅛ in., as shown by lightly etching a smoothed surface. The Rockwell hardness of the core is B-91 to 93 and of the hardened corners, C-54 to 58. The hardened area is cementitic on the surface and martensitic below the surface, while the core is pearlitic.

As previously mentioned it is thought that molybdenum has a tendency to nodulize the graphite flakes when added as an alloy to gray iron. This does not appear to be true in these castings where only 0.25% is used. Even in this quantity, however, it certainly adds to the hardenability.

After these rings are hardened, they are face ground, removing about 0.010 in. to a mirror finish. There is no grinding on the outside diameter or machining on the inside diameter. In hardening there is no perceptible out-of-round distortion.

Graphite Distribution in Hardened Case (Left) and Unhardened Core (Right). Unetched; magnified 100 diameters

Beads of Lapis, Carnelian and Gold; Pendant of Gold, Partly Enameled and Set With Lapis, Carnelian, Garnet and Turquoise. Its back is elaborately engraved. Egyptian; 1900 B.C.

All photographs are Hans Van Nes, kindly loaned by Metropolitan Museum of Art, New York

METALS IN JEWELRY

of ancient craftsmanship

By Frank T. Sisco
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Alloys of Iron Research
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THE LOVE OF THE HUMAN BEING FOR ornamentation and display is deep-seated and ancient; neolithic man and all his descendants have decked themselves and their families with jewelry of various types and materials. Personal adornment became common at an uncertain ancient time; the fact, however, that many primitive people have worn jewelry even though they considered clothes unnecessary indicates that its origin probably goes back to *pithecanthropus erectus*. Archeologists are not agreed whether the wearing of jewelry resulted from vanity plus an inherent desire on the part of *homo sapiens* to demonstrate superiority by displaying his personal wealth, or whether it evolved from the wearing of charms and amulets. Self-preservation is man's strongest instinct, and fear of the unknown is a powerful motive in determining human behavior; it is likely, therefore, that early ornamentation was primarily to please beneficent spirits and ward off the evil ones, and that the wearing of jewelry for ostentation evolved from this.

Metals Used for Jewelry

Nearly all the common metals and alloys have at one time or another been used for jewelry. Gold, of course, is and always has been the most highly prized, with silver generally ranking next. Copper and its alloys have been used widely; iron has been employed rarely, more often because other metals were scarce than because it possessed any properties that made it a competitor of the more precious metals. Although this is generally true, an exception must be made in the case of meteoric iron which, despite the fact that it is more difficult to work than gold, silver, copper, or most of the alloys of these three metals, has the outstanding advantage that it "comes from heaven". This supernatural origin gave it special efficacy in protecting against evil; hence it was greatly prized for charms and amulets. Although used infrequently for ornamental purposes, necklaces and other jewelry dating as early as 5000 B.C. have been found in which meteoric iron was used together with gold. In addition, there is considerable folklore from the period 4000 B.C. to A.D. 1000 confirming the high talismanic value of meteoric iron.

It is unnecessary to emphasize the advantages of gold and silver for jewelry. Both metals are very malleable and could readily be worked into intricate shapes by hand, using only the most primitive tools. Both have a pleasing color and are resistant to corrosion — gold more than silver — by the atmosphere and when worn next to the skin. In addition, both have always been comparatively scarce despite the fact that they are widely distributed. Intrinsic value is important because a strong motiva-

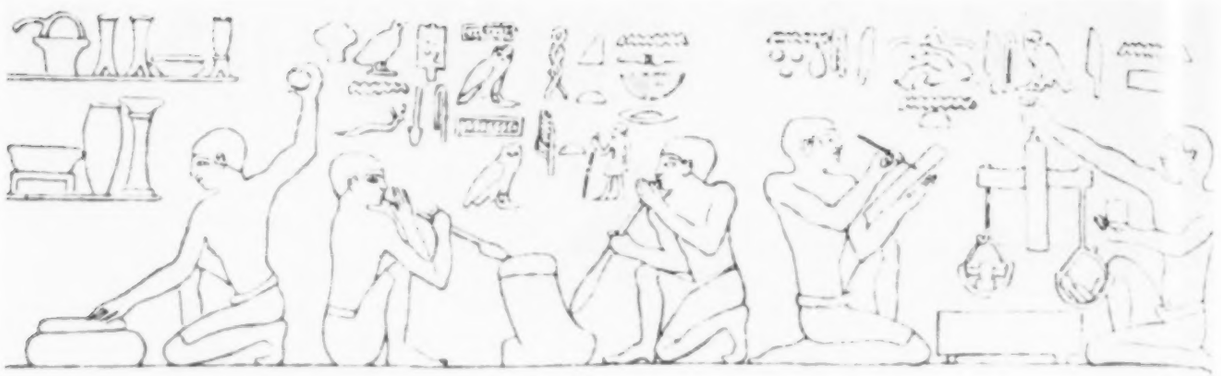

Fig. 1 — Egyptian Goldsmith's Shop. Left to right: Making gold leaf, melting gold with blow-pipe, engraving, and weighing. (From Neuberger's "Technical Arts and Sciences of the Ancients")

tion in owning jewelry is that it permits the owner to have considerable negotiable wealth in readily transportable form.

Although native gold of reasonably high purity is found throughout the world, much of the ancient jewelry was a natural alloy containing 10 to 35% silver, corresponding approximately to our present-day 20 to 14 carat alloy. Owing to its hardness and superior wear resistance — 25% silver practically doubles the hardness of cold-worked gold — this natural alloy, known as *electrum*, was even more highly prized than high-purity gold, and when metallurgical knowledge had advanced sufficiently, it was made artificially and copper was also used to harden the gold. Electrum, and gold hardened by copper, are ideal materials for jewelry; they are corrosion resistant, very malleable, and their color may be varied by proper selection of the alloy from reddish yellow to a greenish white.

Copper, owing to its pleasing color, its high ductility, and a comparatively good corrosion resistance, was used as early as 5000 B.C., and various copper-rich alloys of copper and tin somewhat later. Much beautiful jewelry was produced with this metal and its alloys at all periods of history. Because of the superior hardness of cold-worked bronze and copper (especially if the copper contained small amounts of arsenic, oxygen, and other impurities, as most ancient copper did) as compared with the precious metals, copper and its alloys were used far more widely by our ancestors for tools, weapons, and body armor, and for cups, vases, dishes, and other utensils than for pure ornamentation.

Low carbon iron, produced by the low temperature reduction of iron ore, was used by all ancient and medieval peoples (after about 1200 B.C.) for tools, weapons, and hundreds of ornamental applications, some of which can be ranked among the finest art metal work ever produced. For example, the altar screens, rejas, door and other hardware, fences, gates, railings and the like, especially for churches in 13th to 16th century France, Germany, Italy and Spain, are incomparable. However, soft iron has rarely been used for jewelry. Europeans of the late Hallstatt (*circa* 800 to 500 B.C.) and the La Tène periods (500 to 100 B.C.) used iron for brooches, pins, buckles, and a few other common articles some of which were finely wrought; and in Germany, and to some extent in the United States, in the late 18th and early 19th centuries when other metals were scarce, cast iron was used with considerable artistic success for medals, small statuary, fire backs, and in a few instances for jewelry. Some very fine specimens of bracelets, necklaces, rings, and other cast iron jewelry, made in Germany during this period, were assembled by Professor LAMPRECHT, whose collection is now owned by the American Cast Iron Pipe Co. of Birmingham, Ala.

Metal Working and the Art of the Jeweler

Although fashions in jewelry have changed at various times and places, a definite continuity in the jeweler's art is evident since at least 4000 B.C. Necklaces, bracelets, and ear-rings are, and always have been, universal — as are hairpins, pendants, pectorals (breast ornaments), rings, buckles, brooches, and various kinds of plaques and pins for ornamenting clothes. Anklets were worn by nearly all ancient peoples but disappeared, except among

Fig. — Egyptian Necklace, Representative of the Hellenistic Period (300 B.C.) — an Enlarged View Showing Details of Chain and Granulation

so-called savages, with the coming of Christianity. Today the anklet has reappeared although it is by no means common.

There is one outstanding difference between present-day jewelry and that of 3000 to 6000 years ago: Since the Renaissance, when faceting began, gems have increased steadily in importance until at present the setting is decidedly subordinate to the stone. In ancient jewelry the artistic genius of the craftsman was devoted chiefly to the metal work; gems, if used at all, were usually uncut and unimportant (except in Egypt and other eastern Mediterranean localities where the monotony of a sunny white landscape and its architecture created a strong desire for color in jewelry and where, consequently, stones and enamel of various colors were favored). An excellent example of this is shown on page 440, a pectoral which belonged to the daughter of Se'n Wosret II, Pharaoh of Egypt in 1900 B.C. Small pieces of lapis lazuli, carnelian, garnet, and turquoise are inlaid in enamel to produce the two falcons, the figure of the king, and other sections of the pectoral. On the back the gold is elaborately engraved. The beads are lapis lazuli, carnelian, and gold.

Practically every present-day technique of the goldsmith's and silversmith's art was practiced as early as 3000 B.C.; some are considerably older. The manufacture of gold, silver, and electrum foil is certainly prehistoric; by 3000 B.C. foil less than 0.00004 in. thick was common, as shown by the necklace of Queen Shubad excavated at Ur in Mesopotamia and now at the Metropolitan Museum of Art. This is a string of lapis lazuli and carnelian beads from which are suspended leaves of the beech tree, in gold foil. "Gilding", by covering wooden and other objects with gold leaf, was practiced as early as 3000 B.C. in Egypt.

Gold beating was carried on by the ancients by the same technique as is used now; the metal was hammered into sheets, which were piled with leather or parchment in alternate layers; the pile was then beaten with a stone or hammer. Figure 1 shows an Egyptian goldsmith's shop as pictured on the wall of a tomb closed about 2500 B.C.

In such techniques as inlaying, engraving, embossing, chasing, and in intaglio work with gold, silver, and electrum the craftsmen of 4000 years ago, especially in Egypt and Western Asia, have never been surpassed and rarely equaled. In enameling, and especially in cloisonné, however, the ancients did not recognize the importance of the coefficient of expansion of the enamel in relation to that of the metal, consequently much ancient enamel has cracked or has fallen out of its setting during the centuries.

A large part of the fine work of the early craftsmen was due to their skill in chain making and in granulation. There is no evidence that wire drawing with a die was practiced before the 10th century A.D.; on the contrary, there is much evidence that all ancient wire was

Fig. 3 — Greek Gold Diadem, About 350 B.C., Showing Figures of Dionysus and Ariadne, and Choirs of Musicians

hand-hammered from thin strips of foil and that the resulting short wires were so cleverly soldered or welded together that the joints can rarely be detected. The Egyptians made chains as early as the fifth dynasty (*circa* 3200 B.C.), and chains have been widely used for jewelry ever since. A good example of the Egyptian chain maker's skill is shown by the Ptolemaic necklace pictured (enlarged) in Fig. 2. Examination with a low-power magnifier disclosed evidences of hammering, but no soldered joints could be detected.

As fine metal work as has ever been made is the granulation in gold, which began in Egypt in the twelfth dynasty (2000 to 1800 B.C.), and which was practiced there for more than 2000 years. Some of this work is well shown in Fig. 2. It is fairly certain that the gold was melted and granulated as fine beads by pouring into water, but authorities are not agreed on the method of attaching the beads to the medallion; some believe that the beads were heated to incipient melting and were sweated on; others claim that they were soldered. In the necklace shown in this article there is no evidence of soldering; it is, however, certain that the beads were put on individually.

In addition to being hot worked and cold worked, metals were melted and cast in molds as early as 4000 to 3500 B.C. Copper ax heads were cast with sockets for hafting in Sumer (between the Tigris and Euphrates Rivers) in 3500 B.C., and hollow copper and gold statues and statuettes were cast by the "lost wax" process in Egypt almost as early as this. Casting, although used widely for utensils, tools, and weapons, was rarely used for jewelry.

Ancient and Medieval Jewelry as Art

Production of artistic metal work depends upon two factors — first, competent artisans with an original sense of design and second, a country that is prosperous and at peace. In the ancient world these conditions were fulfilled best in Egypt. For more than 3000 years the civilization along the Nile grew and prospered with only one major invasion, that of the Hyksos about 1800 B.C., to disturb it. As a result, the artistic metal working of the Egyptians is considered by many to be the finest ever produced. With a thousand years of development and with the craftsmen carefully trained and closely organized in guilds under state control, artistic metal working reached its highest development in the twelfth dynasty (2000 to 1800 B.C.). The pectoral photographed on page 440 represents the work of this period, which shows a delicacy, taste, sense of proportion, and a blending of colors, that probably has never been surpassed. With the Hyksos invasion and the accompanying chaos the art of the jeweler declined. There was a renaissance during the eighteenth dynasty (1580 to 1350 B.C.), but as compared with the twelfth, the metal work, although fine, was becoming somewhat artificial. As one authority puts it: "Eighteenth dynasty jewelry shows that Egyptian women were still beautiful and charming but were no longer young." Except for some fine granulation in the Ptolemaic period, taste — and in large measure workmanship — declined.

Babylonian craftsmen of 3000 to 1000 B.C. were probably better metallurgists and better technicians than their Egyptian contemporaries

were far behind in artistic genius. Babylonian jewelry, although making use of rosettes and geometrical designs in filigree, was usually heavy and solid. In style it was surprisingly like the jewelry of Victorian England. Babylonia, in contrast to Egypt, was subject during these 2000 years to almost constant war.

The early Greeks and their predecessors on the islands of the Aegean and in Crete were competent and occasionally fine metal workers. Although the people of the Minoan Age (3000 to 1500 B.C.) developed some original designs, especially in gold and silver cups and, more rarely, in small jewelry, their skill and artistic development were inferior to those of the Egyptians and Babylonians whose work they imitated. During this period the art of the Greeks and their forerunners was more Asiatic than European, but by the fifth century B.C. it was approaching its apogee and produced some finely chased gold and silver work. In the fourth century the Greeks developed decoration in relief to the highest point it had reached. Historical and mythological subjects, flowers and foliage, animals and birds, circular, spiral, and other geometrical designs were beaten through the walls in high relief so that the design was visible on both sides. Figure 3 shows such work on a diadem, made sometime near 350 B.C.

Except for Western Asia and the shores of the Mediterranean, the jewelry of the Western world was primitive until several centuries after the beginning of the Christian Era. From the standpoint of metal working none of this is interesting except the metal carving practiced by the Scythians, who lived in South Russia in the fifth century B.C. Examples of their work are shown in Fig. 4. These stags, which apparently were used for ornamenting garments, were carved by a technique which in all probability was practically the same as that used for carving bone or wood.

With the establishment of the Eastern Roman Empire by Constantine and the growth of Byzantium, artisans collected at Constantinople from all over the East. Byzantine jewelry, mostly religious in character, was outstanding in the early Middle Ages. The jewelry was simple and massive; strangely there seems to be little connection between the Greek and Roman naturalistic decoration of the early Christian Era and the heavy style used by the Byzantine jewelers several centuries later. The best Byzantine jewelry was produced in the sixth and eleventh centuries A.D.; by the twelfth century both the precious metals and the jeweler's art had been debased.

Jewelers of Europe between the fifth and twelfth centuries were skilled but displayed little originality. Considerable copper and bronze, and some iron, were used during this time. Much of the early medieval European work had a sacred connotation; chalices, caskets, crosses, and reliquaries were made in large numbers, and crowns and tiaras were designed for the numerous petty kings.

This brief article about the origins of metallic jewelry should not close without a mention of the fine jewelry produced during the Renaissance in France, Italy, Holland, and especially at Augsburg and Nuremberg in Germany. This was a period of splendor and showy display, and large quantities of jewelry were worn by men as well as by women. Extensive use was made of precious and semi-precious stones and colorful enamels. Artists of the first rank —da Vinci, Cellini, Caradosso, Solis, de Bry, Delaume, and others —made designs to be copied and wrought by the jewelers. In general, however, the metal working itself was nowhere near as good; it was no better than what had been habitual in Egypt 3000 years before. It is foolhardy for a 1941 metallurgist to attempt to judge the artistic merit of this Renaissance jewelry. It was intricate and much of it was garish, showy, and often even tawdry. The Renaissance was a period of ostentation, and the jewelry fitted those who wore it. Doubtless most individuals today would think it is beautiful.

Fig. 4 — Carved Gold Stags From South Russia, Scythian 5th Century B.C. (Full Size)

Quenching Fixture in Operation on a Large Bearing Race
Photograph courtesy Timken Roller Bearing Co.

HARDENABILITY TESTS

correlation

each to each

By Walter E. Jominy
Metallurgy Dept., Research Laboratories
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AN ARTICLE IN THE NOVEMBER 1940 issue of METAL PROGRESS, entitled "Commercial Aspects of Hardenability Tests", attempted to show how the data acquired by these relatively new test procedures could be used in selecting steel for a given part of required hardness, either at the surface or at some specified location under the surface. Since several methods are in use, it is now proper to compare them, and to discover how results acquired by men in one place using one method can be correlated with results acquired elsewhere with another method.

Of the number of different methods now in use, the commonest and the one requiring the least equipment is that of quenching round bars, sectioning these bars and then making a hardness traverse across the section. Suitability of this method for a given steel depends on the size of the round selected. It can be used on plain carbon or alloy steels of deep or shallow hardening grade, but it is not suitable for measuring steels in the carburized condition. The difficulties with the method are that different laboratories may get somewhat different results because of differences in the severity of the quench, differences in the heating furnace atmospheres causing various types of scale, differences in surface finish, and dangers of drawing the temper during sectioning. For the deep hardening alloy steels this method is not very suitable unless very large sizes are used and these require long heating periods and are difficult to cut open after hardening.

Burns, Moore and Archer suggested the use of the sectioning method on a 1-in. round bar, water quenched. They attempt to control the quenching operation as much as possible without special equipment. A mathematical expression is used for the hardness obtained after sectioning which includes the surface hardness, the area under the hardenability curve, and the center hardness. This "S-A-C" expression then reports the quantitative measurements for the given steel. This test is especially suitable for water hardening steels and cannot of course be used on steels which will harden through to the center when quenched in water. It cannot, therefore, be used on most of the medium carbon alloy steels.

The Shepherd test, which preceded any of the more or less standardized methods, is the same type. In it a $\frac{3}{4}$-in. round bar is quenched from 1600° F. in oil, then requenched in brine and sectioned, then etched with 50% HCl in water to show the depth of hardness. Discs of stepped thickness may be used instead of the round bar. In either case this test is only useful for shallow hardening steels.

The method of Grossmann is an

Correlation for Shallow Hardening Steels

SHEPHERD	L-BAR
2/32 in.	5/32 in.
3/32	7/32
4/32	10/32
5/32	12/32
6/32	14/32
7/32	15/32
9/32	1/2
10/32	17/32

application of the sectioning method in which several bars of different sizes must be hardened and sectioned in order to obtain the size of bar in which the center hardness changes abruptly with small changes in diameter. This bar size is called the critical size and is a measure of the hardenability of the steel under investigation.

The critical size may be calculated if three (or preferably four or more) bar sizes have been sectioned. The mathematical solution can be easily applied to a series of traverses like those shown in Fig. 1 of S.A.E. 1050 steel but cannot be applied to the traverses of the type shown in Fig. 2 of 5145. Grossmann's method requires more work than the others and if a mathematical calculation is to be used the measurements must be very carefully made; the resulting determination is, however, quite accurate.

The end-quench method used in the General Motors' research laboratory is perhaps the easiest and quickest method for the information gained. We heat the specimen (Fig. 3) to the desired hardening temperature and drop it endwise into a fixture that holds the lower end ½ in. above a spray nozzle. The quenching medium is water at 75° F. The opening through which the water travels is ½ in. diameter and the height of the water column before placing the sample in the fixture is 2½ in. In this way the quenching medium hits the bottom end of the sample only, and practically all of the heat is extracted from the face of that quenched end. After cooling a small flat is ground 0.015 in. deep along the entire length of the bar and Rockwell readings made at ⅛-in. intervals from the hard end.

In one test — which does not require sectioning of the bar — we obtain the hardness developed with the steel in question with all rates of cooling from over 500° per sec. to 4° F. per sec. The method is especially well suited to alloy steels whose critical cooling rates are in the range from about 150° F. per sec. to 4° F. per sec., which covers just about all of the common medium carbon alloy steels. In this range the rate of change of cooling rate is low, so that accurate results can easily be obtained.

In cooling rates above 150° F. per sec. the rate of change is rather fast, so that the bar is not as well suited to steels in this range which are mainly the plain carbon shallow hardening steels. For shallow hardening steels we have found our "L-bar" shown in Fig. 3 to be very satisfactory. The same hardenability equipment is used for this bar as for the standard bar. The only difference in the procedure is that the free height of the water column sprayed into it is raised from the 2½ in. used for quenching the standard bar to 4 in.

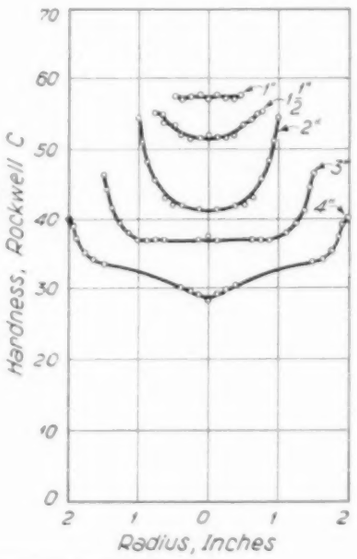

Fig. 2 — Hardness Traverses Across Diameters of Oil Quenched "Deep Hardening" Chromium Steel (S.A.E. 5145)

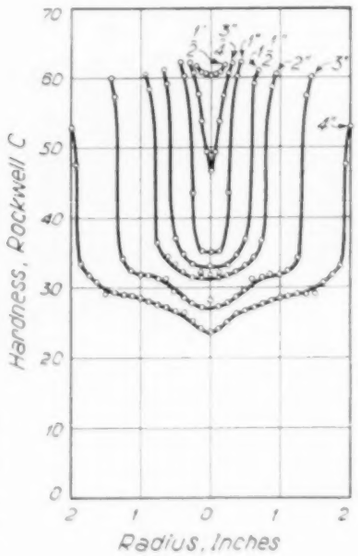

Fig. 1 — Hardness Traverses Across Diameter of Broken Bars of "Shallow Hardening" Steel (0.50% Carbon, S.A.E. 1050). Round bars of various sizes, water quenched from 1530° F.

This bar provides a more sensitive means for measuring hardenability than a sectioned 1-in. round, since the change in cooling rate is about three times more gradual in the L-type bar. This may be observed from Fig. 4 which shows the locations on the two bars that have the same cooling rates.

Both our standard bar and L-bar can be used to measure the hardenability of a carburizing steel in the carburized condition. In fact this method of end cooling is the only one that can be used for carburized steels.

Transposition of Methods

We will now attempt to indicate how this can be done, even though more data are needed to be certain of doing this accurately in all cases.

In transposing, the question arises as to whether we should use the cooling rates at 1300° F., those at

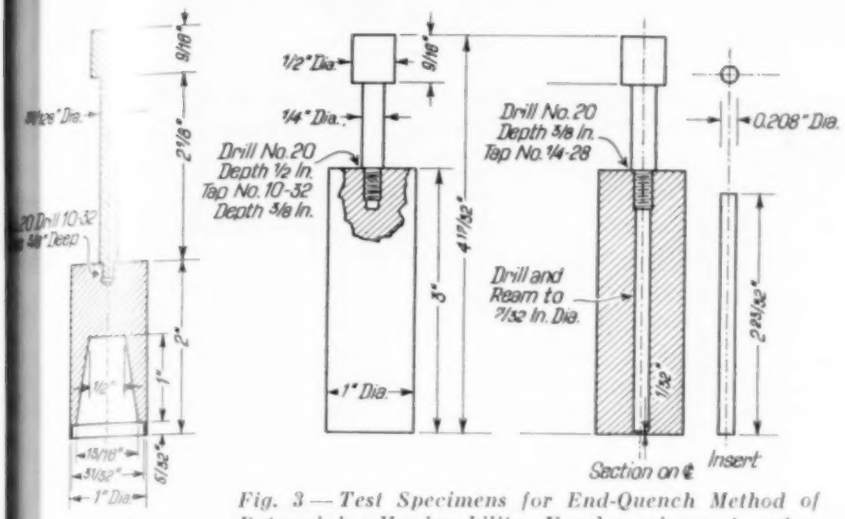

Fig. 3 — Test Specimens for End-Quench Method of Determining Hardenability. Usual specimen at center; L-bar for steels of low hardenability at left; drilled bar at right for steels available only in small sizes

1000° F., the time to cool from 1100 to 900° F., or the time to cool to the half-temperature point. (The half-temperature point is obtained by averaging the temperature of the quenching medium and the temperature of the steel as it leaves the hardening furnace.)

In our comparisons, we have used either the cooling rate at 1300° F. or that at 1000° F., our choice being determined by data available in the literature for the particular size and location of the bar in question. Our reason for using these is that for the many tests we have made on bars of different shapes at locations where the rates of cooling at 1300° F. (or at 1000° F.) have been the same, the hardnesses at these locations have checked fairly well. In a publication of previous work in the ASM book "Hardenability of Alloy Steels", p. 66, three steels, S.A.E. 1050, 3145 and 5145, were hardened in the form of round bars in sizes ranging from ½ in. round to 4 in. round. These bars were then sectioned and hardness traverses made. (Results for two of these steels are reproduced as Fig. 1 and 2 in this article.) From the same steels our standard hardenability bar was made and tested on our hardenability fixture. It was found that for each steel the hardness at the center of the various rounds agreed with that at the location

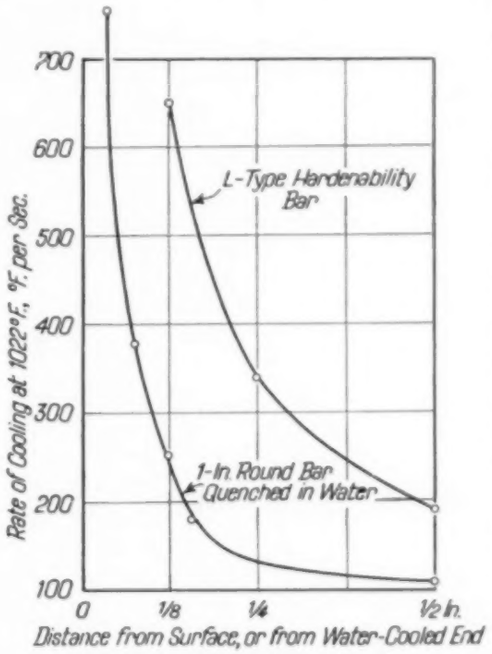

Fig. 4 — Cooling Rates of Usual End-Quenched Specimen and L-Type Specimen Show That Latter Has a More Gradual Change in Rate Away From the Quenched Surface

in the end-cooled hardenability bar where the rates of cooling at 1300° F. were identical.

We also tested in the General Motors' end-quench fixture a number of the steels studied by KLAIN and LORIG (*Transactions* ASM, Vol. 28, p. 83). Messrs. KLAIN and LORIG had made hardness traverses on round bars of several steels, the rounds being ½, 1, 2 and 3 in. for each steel, and we obtained pieces of the 1-in. bars used by them. These bars were cut into pieces 3 in. long and standard hardenability test specimens made from them. The heating temperatures were the same as used by KLAIN and LORIG for the 2-in. round bars. The total time in the furnace for all bars was 55 min. Tests were made in duplicate and the readings from the two bars were averaged. Results of the two laboratories and the two methods checked, usually within one point on the Rockwell C-scale.

In comparing the data from our tests with those of KLAIN and LORIG it became apparent that the quench employed by them was quite severe — particularly their oil quench. This required the use of a somewhat modified factor for conversion from our bar to the center hardness of the rounds. This modification, however, was small — not being more than $\frac{1}{16}$ in. on our bar, except with the 3-in. round, oil-quenched bar where the factor was modified $\frac{1}{8}$ in. In all cases the modification was toward higher cooling rates, indicating a rather severe quench.

Results obtained by the two methods are placed on the curve sheet (Fig. 5 to 8). On these the steels have been arranged in the order of their center hardnesses as determined by KLAIN and LORIG. For each steel there is also plotted the center hardness indicated from the end-quenched specimen.

Figure 5 contains the steels in the 3-in. round size. Center hardnesses as determined by KLAIN and LORIG are indicated by the circles and the corresponding hardnesses from our bars are indicated by the crosses. It will be observed

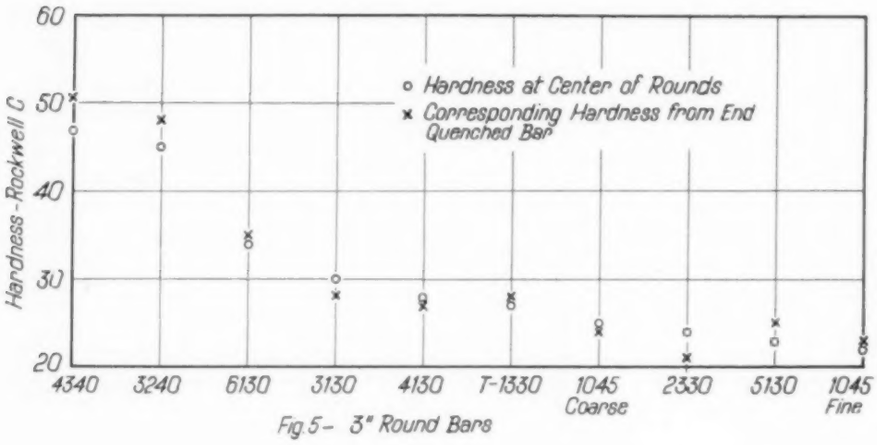

Fig. 5 – 3" Round Bars

Fig. 5 to 8 — Comparisons of Hardness Ratings of a Series of Steels as Determined by Immersion Quenching and by End-Quenching. Note that order of the steels varies with size, and arranged according to hardness at center after immersion quenching

that quite good agreement exists between the two methods, especially when it is remembered that it is not uncommon (in the method used by KLAIN and LORIG) to find variations in hardness for similar locations in the same bar of 3 points Rockwell C (and occasionally as much as 7 points). Furthermore, there doubtless were varying amounts and kinds of scale on these bars as they were placed in the quenching fixture by KLAIN and LORIG, especially since no precautions were taken to have a uniform finish on the bars. The variation in amount of scale undoubtedly affects the rate of cooling — especially when oil quenching. In our end-quenched bars there is practically no scale and the cooled surface always has the same finish.

Figure 6 contains the same steels in the order of the center hardness of the 2-in. round bars. Here again there is good agreement except for steel 2330 where there is a difference of 7 points. We do not have any factual information as to why this difference should occur. Our first guess was that segregation existed, but this was not found. Another suggested explanation is that a low heating temperature and resistance to scaling resulted in less scale on the 2330 steel, thereby causing a relatively faster quench when cooled all over in a spray.

Good agreement is shown between the hardnesses of the 1-in. and the ½-in. round bars (Fig. 7 and 8) side-quenched in a spray fixture at Battelle Memorial Institute and end-quenched in a spray fixture at General Motors Research Laboratory.

It appears that we are justified in concluding that there is good agreement between the center hardnesses of various sized bars as obtained by the transverse method of measurement and the hardness at the point of corresponding cooling rate on the end-quenched test bar.

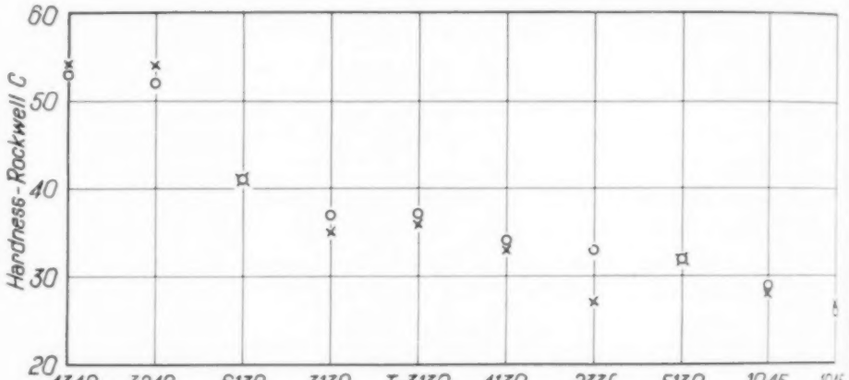

Fig. 6 – 2" Round Bars

Identification of Steels Tested in Fig. 5 to 8

S.A.E. Steel	Chemical Composition							Quenching Temperature
	C	Mn	Cr	Ni	Mo	V	Si	
1040	0.39	0.81	—	—	—	—	—	1550° F.
1045	0.47	0.83	0.22	—	—	—	—	1525
T-1340	0.40	1.67	—	—	—	—	0.21	1525
X-3140	0.41	0.80	0.85	1.36	—	—	0.17	1525
3145	0.44	0.78	0.62	1.28	—	—	0.19	1530
4145	0.45	0.80	0.94	—	0.17	—	0.16	1550
4640	0.40	0.67	—	1.80	0.24	—	0.20	1550
5140	0.38	0.71	0.92	—	—	—	0.17	1550
5145	0.45	0.90	1.01	—	—	—	0.18	1530
6145	0.49	0.71	0.95	—	—	0.21	0.21	1550

Correlation of End-Quench and Immersion Quench

Dia. of Round	Quenching Medium	Equivalent *(a)*	
		Scott	Klain & Lorig
3 in.	Oil	1 7/8 in.	1 1/8 in.
2	Oil	3/4	1/2
1	Oil	3/8	1/8
1/2	Oil	5/32	1/8
3 in.	Water	3/4 in.	3/4 in.
2	Water	1/2	1/2
1	Water	1/8	1/8
1/2	Water	1/16	1/16

(a) Location on end-cooled bar where rate of cooling is the same as the center of bars measured by the investigators noted.

One point of interest, when taking center hardness as a measure of hardenability, is that these steels do not have the same relative hardenability in the 2-in. round size as in the 3-in. round size, or in the 1-in. or ½-in. size. Each size seems to rate the steels in different order. However, if these steels are plotted according to expected center hardness from the end-quenched specimens, they will have exactly the same order of relative hardenability in the 3-in. and the 2-in. sizes and (except for transposing of S.A.E. 2330 steel from 10th to 7th place) they have the same order of hardenability in 1-in. rounds. Transposed hardnesses are affected strongly by carbon content in the ½-in. rounds, so the same order of hardenability is not maintained.

One thing should be pointed out here regarding the *time* consumed in making these tests. The data obtained with the end-cooling method required less than one-tenth the time needed to obtain the same information when employing the method used by Klain and Lorig. In fact, in addition to the data indicated, we can also determine from the end-cooled bar the hardness to be expected at the center of a 4-in., a 2½-in. round bar, or any intermediate size quenched in oil or water.

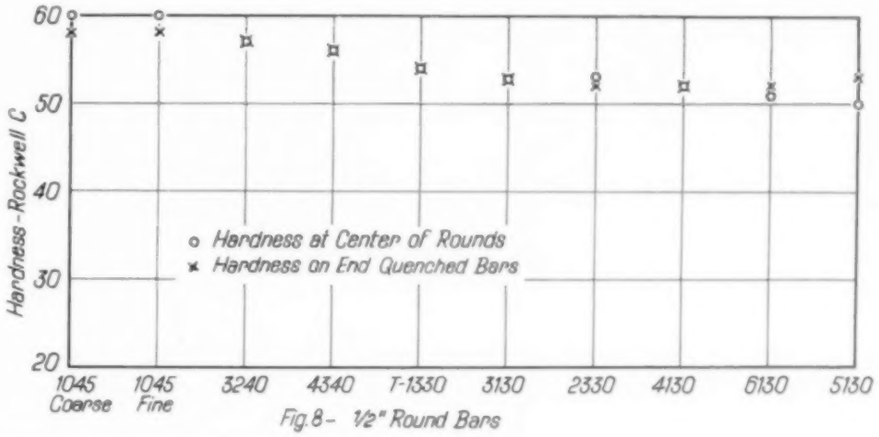

Fig. 8 – ½" Round Bars

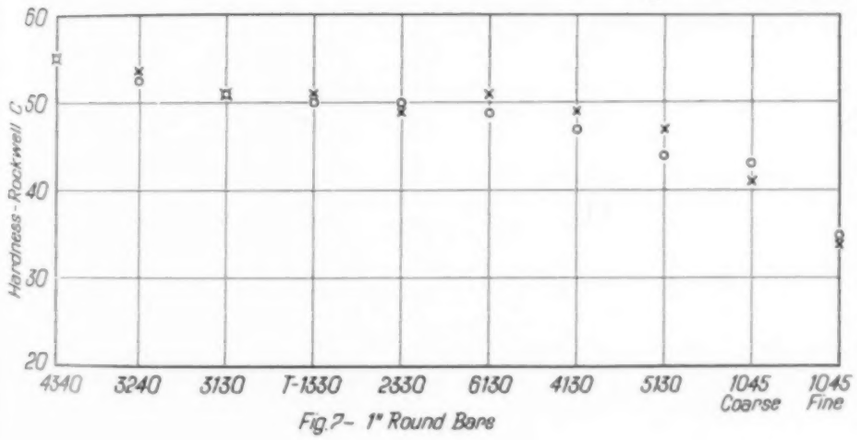

Fig. 7 – 1" Round Bars

In transposing from the one method to the other it is important to remember that many factors other than the hardenability of the steel affect the hardness penetration on round bars quenched in oil or water and that these do not affect the end-cooled bar. It is especially important that pretreatment of the specimens should be identical. Consequently, it is hazardous to present a table showing a relationship between the location of hardness on end-cooled bars with that at the center of various sized bars when quenched in oil or water. However, since it is quite often useful to transpose, such a table is given above, showing corresponding locations by points of corresponding cooling rates at 1300° F. (or 1000° F. as determined at the center of bar sizes by Scott) and which we have found in many tests to have corresponding hardness values. There are also given the points of corresponding hardness as determined at the center of bars hardened by Klain and Lorig and our values.

Tests have been made comparing our L-bar with the values obtained with the Shepherd "P.F." test. On the basis of the results obtained, we believe that locations of equal rates of cooling at 1000° F. may be expected to give the same hardness. We have therefore prepared another table (page 447) which should be considered as approximate only, since the finish on the Shepherd bar, the scale on the surface, and the manner of quenching, affect the results.

THE FREE-MACHINING

stainless

steels

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THE REMARKABLE DEVELOPMENT IN the use of stainless steels during the last decade has been largely due to a better knowledge by fabricators of how to work and machine these alloys, coupled with the ceaseless effort of producers to improve their working qualities. When these alloys were first introduced, it was quickly found that they were quite difficult to form, and some of them were particularly difficult to machine; in consequence, fabricating and machining costs were high, which restricted their adoption for many applications. Like many other industrial problems, it was not long before ingenuity found a means to improve their machining characteristics greatly.

Poor machinability of the stainless steels is not due to their inherent hardness, but rather to the manner in which the chips adhere to and build-up on the cutting edge of tools, resulting in early failures from "burning". All the stainless steels have high coefficients of friction and tend to seize any unlubricated metal surface with which they are brought in moving contact. This becomes more marked as pressure and temperature are increased. This same tendency causes difficulty in grinding, due to the chips adhering to the grits, thus "loading" the wheel.

The effect of sulphur, in combination with phosphorus, on the machining characteristics of carbon steels was well known at the time stainless steel was introduced, and it was thought that these elements would also improve the latter steels. This proved to be true; however, whereas about 0.12% sulphur and a like amount of phosphorus produced free-cutting characteristics in the carbon steels, it was found by F. R. PALMER that this amount was not sufficient to produce a similar effect on a low carbon 14% chromium stainless steel. In his 1928 article in *Transactions*, A.S.S.T., he observed that as the sulphur was increased above 0.12% machining characteristics improved and reached an optimum at about 0.30%. Further, he found that phosphorus gave no beneficial effect in combination with sulphur in these alloys, and as the sulphur was increased above about 0.15%, the hot workability of the steel was impaired. Due to refinements in melting and rolling during the past several years, the hot rolling and forging of the free-machining stainless steels is no great problem today, even though most grades contain sulphur in excess of 0.25%.

Since the introduction of the free-machining stainless steel (12 to 14% Cr) as a result of PALMER's original research, other free-machining grades of stainless steel have been developed, and there are now six different analyses commercially available. These include low carbon and high carbon 12 to 14% chromium, low carbon and high carbon 16 to 18% chromium, and two types of 18% chromium, 8% nickel steel. Sulphur in combination with molybdenum is added to the straight chromium grades to impart free-machining properties; but in the 18-8 grade, two combinations are used—sulphur plus molybdenum, and selenium plus

phosphorus. Typical analyses are shown in Table I.

It is further worthy of remark that the addition of sulphur to the high carbon, straight chromium steels is not as effective in promoting machinability as when added to the lower carbon grades. This is doubtless due to the large amount of abrasive carbide particles present in the matrix of the alloys first mentioned, which rapidly wears the cutting edge of tools and thus largely nullifies the advantages normally obtained.

Microstructure — In melting it is general practice to compound the raw materials, consisting of base scrap, stainless steel scrap, chromium ore or ferrochromium, sulphur or selenium, molybdenum and nickel, in an electric arc or induction furnace. The sulphur is usually added as roll sulphur or iron sulphide (pyrite) in the ladle as the molten metal is tapped from the furnace. Some mills add selenium as ferroselenium in the furnace, although satisfactory recoveries can be obtained by ladle additions. The average recovery for sulphur is 80% and for selenium 45%. As shown by Fig. 1, there is no appreciable segregation of sulphur in the cast ingot, and as the sulphides do not migrate nor are dissipated by subsequent hot rolling and heat treatment, the figure indicates uniform distribution of the particles in the finished bars or forgings, which is essential for best machining properties.

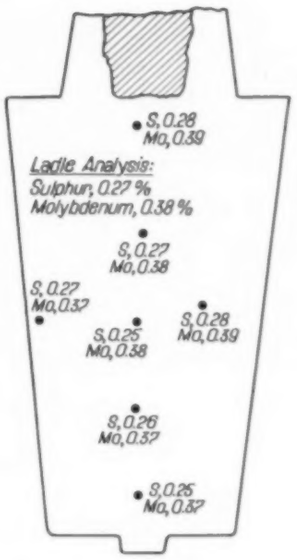


Fig. 1 — Shows Uniform Distribution of Sulphur and Molybdenum in a 10-In. Square Ingot of 12% Cr-FM Stainless

Both sulphur and selenium form insoluble compounds when added to molten stainless steel, and are consequently present in the solidified metal as non-metallic matter uniformly distributed throughout the matrix, as shown by photomicrographs in the Data Sheet, page 459. It will be noted (Fig. B) that in the cast metal the particles are globular, but in the wrought metal (Fig. E) they are elongated in the direction of rolling, which indicates a fairly high degree of plasticity at rolling temperatures. It is generally assumed that the compound formed by sulphur approximates the formula CrS·FeS·MnS. When molybdenum is added in combination with sulphur, a portion of the sulphur may combine with it. Selenium, like sulphur, reacts in the molten metal to form selenides, which are largely insoluble and are present in the solidified metal as non-metallic matter (Fig. J, K and L, page 459).

Although the percentage of sulphur in the free-machining stainless steels is relatively high, no indication is obtained with a sulphur print. It is of interest to note here that the evolution method does not give a satisfactory analysis, as only about half of the sulphur is evolved as hydrogen sulphide; an accurate determination requires a gravimetric or combustion method.

The sulphur or selenide particles are highly stable and are not changed by heat treating. They are generally slate gray and usually they have a duplex structure, as shown by Fig. G and J in the Data Sheet, page 459. Etching reagents for developing the metallic structure of 18-8 will generally attack the inclusions, turning them a uniform black. However, sulphide particles in the straight chromium grades are usually not attacked by the ordinary etching reagents.

The sulphur and selenium inclusions are of fairly low hardness and not abrasive in character, as indicated by micro-hardness tests made in accordance with the method developed by Peters and Knoop (Metal Progress, July 1939, p. 31). Average indentation number H derived from the formula $H = W \div A$ (where W is the applied load in kg., and A is the projected area of indentation in sq.mm.) of both the metal matrix and sulphur and selenide particles in

Table I — Typical Analyses of Free-Machining Stainless Steels

Grade	Type No.	C	Mn	P	S	Si	Cr	Ni	Mo	Se
12% Cr-FM	416	.10	.40	.020	.30	.40	12.75	.25	.35	..
12% Cr-FHC	420-F	.35	.40	.020	.25	.40	13.00	.25	..	..
17% Cr-FM	430-F	.10	.40	.020	.30	.40	16.25	.70	.35	..
17% Cr-FHC	440-F	1.00	.60	.020	.25	.40	17.00	.25	..	..
18-8 S-FM	303	.08	.60	.020	.30	.40	18.50	8.50	.35	..
18-8 Se-FM	303	.08	.60	.120	.020	.50	18.50	8.50	..	.30

samples of commercially annealed material is

Grade	Metal Matrix	Inclusions
12% Cr-FM	H = 158	H = 173
18-8 S-FM	205	230
18-8 Se-FM	220	230

Physical Properties — Sulphur and selenium additions result in important changes in metallurgical characteristics, which should be taken into consideration when processing stainless steels. As pointed out above, the particles are uniformly dispersed in the metal matrix and in wrought material they are elongated in the direction of rolling. It would be expected that these particles, being quite numerous, would adversely affect the physical characteristics of the metal, but actually the only noticeable effect is a slight lowering of elongation, impact strength and reduction of area. However, an exception is the 17% Cr-FM alloy, which shows better impact strength than the regular grade, due to the somewhat higher nickel and lower chromium content.

Typical tensile properties of the various free-machining stainless steels, as well as the corresponding regular grades having no special additions of sulphur and selenium, are given in Table II. It will be noted that there is no great difference in properties, except in impact strength, between the 18-8 S-FM and 18-8 Se-FM grades when tested in the normal direction of rolling. However, owing to the fewer selenide particles in the latter grade, this alloy shows better transverse impact and bending properties.

Cold Work — Since sulphur and selenide particles break up to some degree the continuity of the metal matrix, the free-machining stainless steels are not as suitable for cold upsetting as the regular grades. There is a tendency for upset heads to crack around the periphery, particularly if the upset is rather severe. However, the free-machining stainless steels, especially the 18-8 grades, can be successfully processed into upset screws, provided the chromium-nickel ratio is favorable and the upset not too severe. The 18-8 Se-FM grade is more suitable, due to its lesser tendency to crack in cold forming. They have a distinct advantage when making upset screws with slotted heads, as greater saw life can be obtained, as well as increased production. For best upsetting, the wire should have a thin metallic coating to prevent seizure on the dies; it should not be harder than Rockwell B-90.

All the free-machining stainless steels respond to cold drawing similarly to the regular grades. However, it is advisable to limit drafts to a total of 40%, else there is a tendency for the wire to split and crack. The effect of cold drawing on the tensile properties of 12% Cr-FM and 18-8 S-FM is shown by Fig. 2 and 3.

Hot Work — In general, more care is required for hot working the free-machining stainless steels than for the standard grades. Since their transverse strength is not as great as the regular types there is a greater tendency to check and crack, if all conditions are not favorable. Further, the addition of sulphur and selenium tends to induce red shortness. In

Table II — Properties of the Free-Machining Stainless Steels (Longitudinal Tests)

Grade	Condition	Ultimate Strength	Yield 0.2% Set	Proof Stress	Elongation in 2 In.	Red. of Area	Izod Impact	Brinell Hardness	Endurance Limit
12% Cr	Annealed	78,000	52,500	50,000	32.5	67.0	110.0	152	45,500
	Heat treated	106,000	86,250	70,000	22.0	63.0	85.0	217	55,250
12% Cr-FM	Annealed	75,000	45,500	40,500	30.0	61.5	85.0	152	43,125
	Heat treated	105,000	82,500	68,500	20.0	57.0	70.0	217	55,575
17% Cr	Annealed	69,250	42,500	37,500	35.0	65.0	25.0	141	37,750
	Cold drawn	92,000	75,000	65,000	25.0	60.0	20.0	212	49,000
17% Cr-FM	Annealed	68,000	41,000	36,750	34.0	62.0	35.0	149	38,500
	Cold drawn	95,000	75,000	65,500	16.0	60.0	25.0	217	48,000
18-8	Annealed	85,500	33,500	29,500	60.0	70.0	115.0	156	36,500
	Cold drawn	95,750	62,500	39,000	48.0	67.0	110.0	192	43,500
18-8 S-FM	Annealed	85,000	32,500	29,000	55.0	60.0	73.0 *(a)*	150	35,000
	Cold drawn	100,750	65,500	40,000	45.0	58.0	70.0	192	48,000
18-8 Se-FM	Annealed	87,200	34,500	29,000	60.0	65.0	100.0 *(b)*	140	34,500
	Cold drawn	106,250	68,500	42,500	44.0	57.0	90.0	223	51,000

(a) Cold bend 180° longitudinally; transverse Izod 15 ft-lb.; 100° bend (cracked)
(b) Cold bend 180° longitudinally; transverse Izod 26 ft-lb.; 180° bend (cracked)

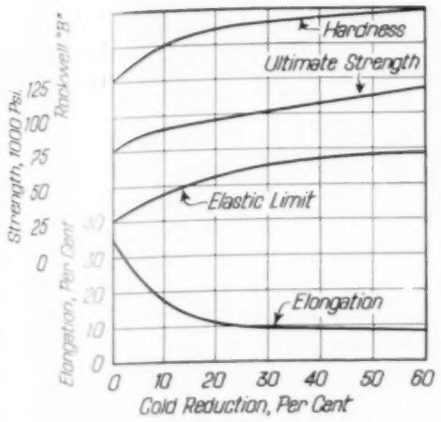


Fig. 2 — Effect of Cold Drawing on Tensile Properties of Annealed 12% Cr-FM Stainless Steel Wire

forging these steels, careful heating is required, as it is important that the metal be uniformly heated before work is started. Temperatures for forging and hot rolling vary somewhat with the grade, but usual practice is to start working from the range of 2050 to 2200° F., and finish above 1650° F. As shown on page 457, it is possible to make rather intricate forgings, and with more careful practice, one can forge these free-machining alloys into almost any shape possible with the regular grades.

Heat Treatment — Sulphur and selenium, in the amounts present in the free-machining stainless steels, do not materially affect their response to heat treatment. Therefore, the same procedures used for processing the corresponding regular grade are applicable. The dilatometer curves in Fig. 4 show that 0.31% sulphur in a regular 12% chromium stainless steel containing molybdenum, does not change the critical point on heating, but prevents the "split transformation" on cooling. This indicates that the critical cooling rate has been changed, thus permitting a faster rate of cooling after annealing the high sulphur alloy. However, its hardening capacity is not affected, as it will normally harden above 375 Brinell when oil quenched from 1750° F.

The 18-8 grades are annealed or softened by heating in the range of 1850 to 2000° F. and rapidly cooled by water quenching. In this condition these alloys possess best corrosion resistance and highest ductility. Their hardness and tensile strength cannot be increased by heat treatment and the only means whereby this can be accomplished is by cold work, such as rolling, drawing or swaging. Normally, the 18-8 FM grades are non-magnetic but when severely cold worked become quite magnetic. Like the regular 18-8, the free-machining grades are susceptible to carbide precipitation when exposed for periods, more or less prolonged, in the temperature range of 900 to 1650° F.; such material, subsequently exposed to severe acid attack, is corroded between the micro grains and fails rapidly. The extent of carbide precipitation in this susceptible material is shown by Fig. 5 (page 456). Normal corrosion resistance can be restored by reheating in the range of 1850 to 2000° F. and water quenching. Carbide precipitation — with consequent susceptibility to intergranular corrosion — can be greatly minimized by holding the carbon below 0.07%.

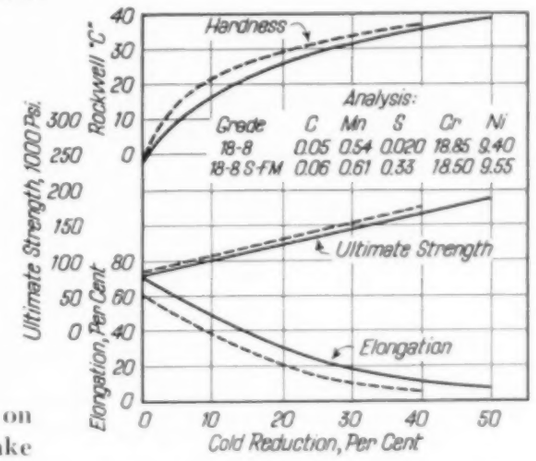


Fig. 3 — Free-Machining and Regular Grades of 18-8 Cold Work Similarly

The damaging effect of heating at 1150° F., for the short period of 30 min., on the resistance of 0.10% C, 18-8 S-FM alloy to 65% boiling nitric acid solution is given in the following

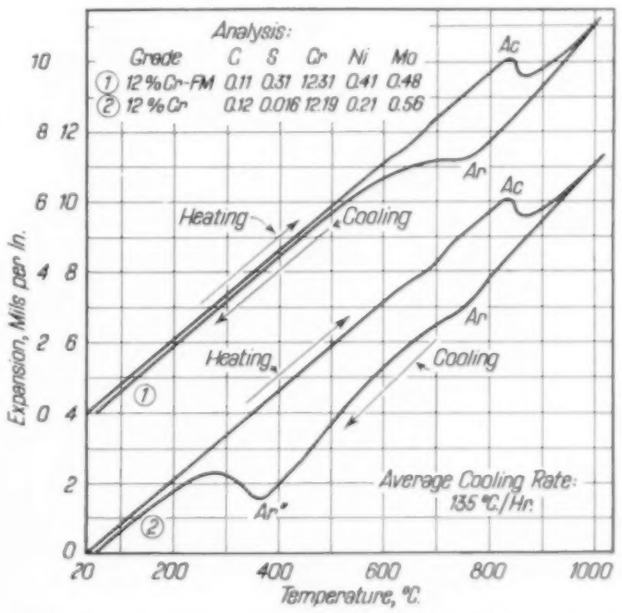


Fig. 4 — Comparison of Heating and Cooling Curves on 12% Cr and 12% Cr-FM Stainless Steels. The Ac points are the same, but the Ar transformation for the 12% Cr grade spreads over a considerable range

figures, in terms of inches penetration per month:

Treatment	1st 48 Hr.	2nd 48 Hr.
Annealed (1950° F.; water quenched)	0.0352 in.	0.0758 in.
As above; then heated to 1400° F. for 30 min.; air cooled	0.0642	0.1660

The 12% Cr-FM alloy — as well as the high carbon, free-machining stainless steels — can be hardened by heating to above 1750° F. and cooling fairly rapidly, such as by oil quenching. A wide range of tensile properties can then be obtained by tempering this material. (See Fig. 6.) To fully soften these alloys, it is necessary to heat above 1525° F. and cool slowly in the furnace to below 1200° F.

The 17% Cr-FM grade is a ferritic alloy (an "iron" rather than a "steel") and cannot be appreciably hardened by heat treatment. It therefore is generally utilized in the annealed condition, or after it has been hardened and toughened somewhat by cold drawing.

Welding — In general, the free-machining stainless steels are not as suitable for welding as the regular grades. The most weldable ones are the 18-8 S-FM and 18-8 Se-FM. Experience has shown that during welding the sulphur and selenium particles tend to decompose and form gases, and cause slight porosity in the deposited metal. Nevertheless, with proper technique strong and ductile welds can be obtained. In arc or gas welding, it is best practice to use regular 18-8 material for electrodes or filler rods, and as shown by Fig. 7, the arc deposited metal is free of sulphide particles.

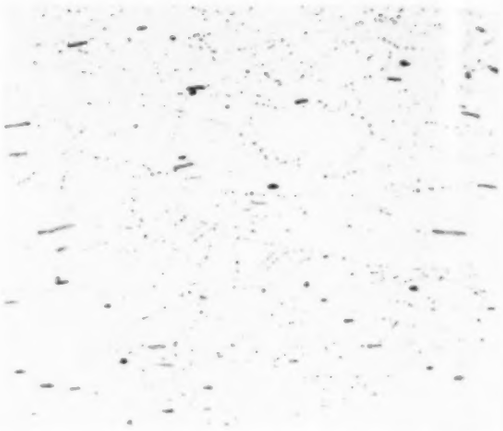


Fig. 5 — Precipitation of Carbides Along Grain Boundaries in 18-8 S-FM Stainless Steel, in Consequence of 30 Min. Heating at 1400° F. Electrolytic NaCl Etch. Magnified 500 diameters

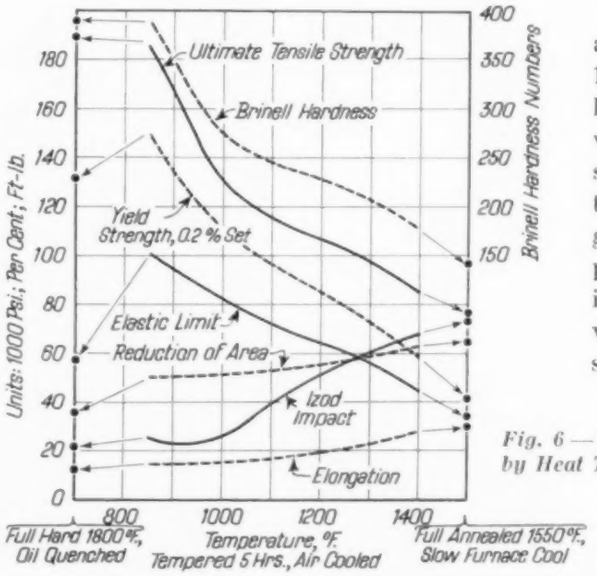


Fig. 6 — Wide Range of Properties by Heat Treating 12% Cr-FM Stainless. Analysis: 0.11% C, 0.50% Mn, 0.30% S, 12.50% Cr, 0.25% Ni

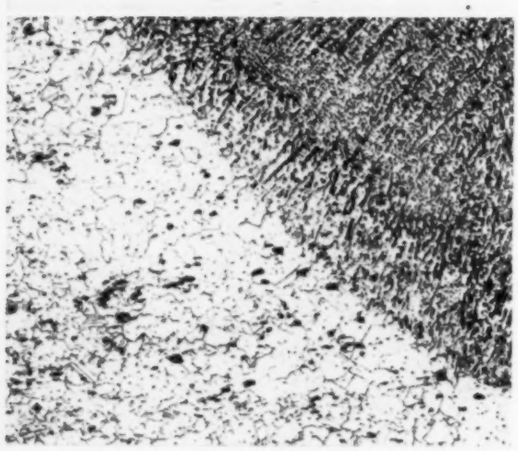


Fig. 7 — Zone of Fusion in 18-8 S-FM Stainless, Arc-Welded With 18-8. Unetched view above (at 200 diameters) shows clean weld at upper right; lower view of same area (at 100 diameters) has been etched with aqua regia

All the free-machining stainless steels can be welded by the electric resistance method, but here again the straight chromium grades are less suitable than the 18-8 types. Table III shows the tensile properties of butt welds on the two 18-8 free-machining grades, as well as the regular type. It will be noted that elongation is lower in the butt weld, this being particularly true with the free-machining grades, as elongation is reduced to nearly one-half of that possessed by the metal outside the weld zone. Despite this, the butt welds withstood a 180° bend, indicating sufficient ductility for most uses.

Machining — As pointed out in a foregoing paragraph, the difficulty experienced in cutting and machining the stainless steels is not

Table III — Tests on Resistance Welded Butt Joints

Property	18-8		18-8 S-FM		18-8 Se-FM	
	Base Metal	Butt Weld	Base Metal	Butt Weld	Base Metal	Butt Weld
Ultimate strength, psi.	90,000	89,500	86,500	81,000	100,000	96,000
Yield strength, 0.2% set, psi.	35,500	38,000	32,750	35,750	33,250	36,500
Elongation, %	60.0	50.0	55.0	34.5	53.5	40.0
Reduction of area, %	70.0	49.0	58.0	33.0	62.5	34.5
Rockwell hardness	B-77	B-78	B-80	B-79	B-78	B-78
Cold bend	180° OK	180° OK	180° OK	180° OK	180° OK	180° OK

due to their inherent hardness, but rather to their toughness, coupled with a relatively high coefficient of friction, resulting in a tendency for chips to adhere to and build up on the tool's cutting edge and cause premature failure from "burning". Addition of sulphur or selenium minimizes these defects and permits machine speeds and feeds impossible with the regular grades. A few of the many parts machined from the free-machining stainless steels are shown in the accompanying halftone (page 458). All these finished parts were made in the production line, and illustrate a very high order of machinability.

It is not clearly understood, but it is generally assumed, that the improvement in machinability is due to the particles present in the metal matrix, which lubricate the cutting edge of tools and, at the same time, cause chips to break more freely. Also, the coefficient of friction is reduced considerably, as evidenced by a lessened tendency to gall and seize in services involving sliding metal parts in contact. It is difficult to evaluate relative frictional properties of metals, but in many cases where the regular stainless steels galled or seized in service, the substitution of one of the free-machining types eliminated the difficulty.

Since their first introduction considerable progress has been made towards producing these alloys with better machining characteristics. Also, the user is constantly devising better

Intricate Shapes Can Be Forged From Free-Machining Stainless Steels, When Correct Practices Are Followed

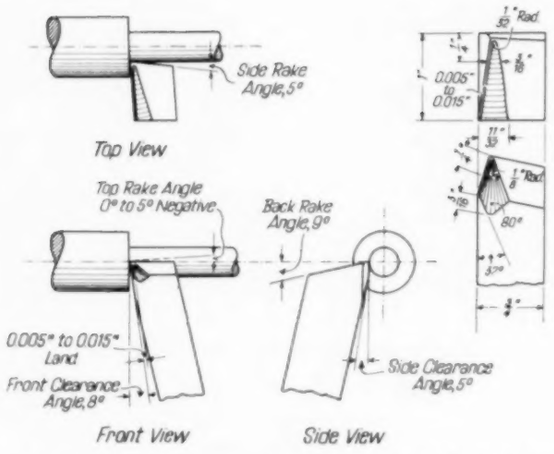


Fig. 8 — Recommended Tool Working Angles and Details of Chip Curler Grooves for Turning

tooling and improved methods for machining. Although acceptable results can be obtained with tooling commonly used for cutting ordinary bessemer screw stock, cutting speeds and feeds can be increased considerably by special tooling.

Of primary importance are the tools made of high speed steel. The 18-4-1 type is the most satisfactory for general use. Cutting tools and work should be lubricated with a sulphur base cutting oil diluted with paraffin oil. Greatly increased tool life is obtained by proper grinding to provide adequate clearances and a groove for chip curler. The grinds and clearances found to be most satisfactory for drilling, forming and turning the free-machining stainless steels are shown by Fig. 8, 9 and 10.

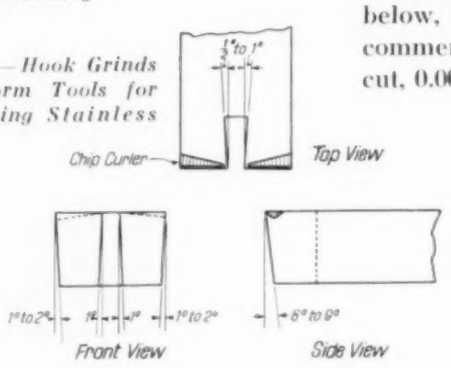


Fig. 9 — Hook Grinds for Form Tools for Machining Stainless

Experience has shown that metal with a hardness slightly above that of the annealed condition can be machined at a higher rate, and at the same time yields a better finish. The free-machining stainless steels possess best machining properties at about 200 Brinell. In the 18-8 grades, this hardness is obtained by cold drawing, and in the straight chromium grades by either heat treatment or cold drawing.

The relative cutting speeds for a tool life of 5 hr. for the various free-machining stainless steels, as well as the corresponding regular grades, in the annealed and cold drawn condition are given below, based on turning tests in a commercial turret lathe using ¼-in. cut, 0.0075-in. feed, chip curler high speed steel tool, sulphur base cutting oil as lubricant. Figures are for surface speeds in feet per minute, and have been kindly supplied by my associate, G. J. Stevens.

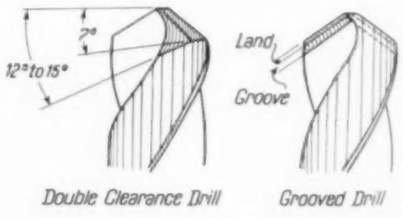


Fig. 10 — Two Methods for Grinding Drills for Free-Machining Stainless Steel

Cutting Speeds for 5-Hr. Life

Grade	Annealed	Cold Drawn
17% Cr	100	105
17% Cr-FM	137	139
12% Cr	105	114
12% Cr-FM	116	123
18-8	86	90
18-8 S-FM	98	105
18-8 Se-FM	80	85

It will be noted that under these conditions the 17% Cr-FM grade exhibits the best machining characteristics and this has been confirmed by commercial shops. One shop reported that on substituting it for the 12% Cr-FM grade, it was able to increase cutting speed by 30% and at the same time secure a better finish and additional tool life. *(Continued on page 500)*

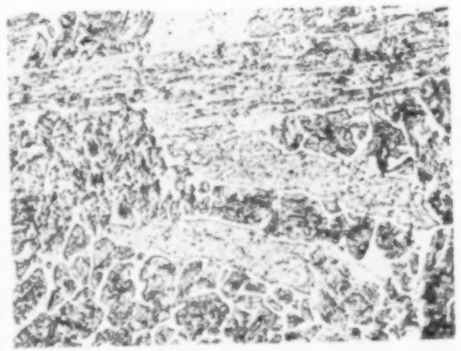
Microstructure of Free-Machining Stainless Steel

(Etched Electrolytically With 10% HCl in Alcohol Except as Noted)

A, B, and C Are Cast 12% Cr Steel

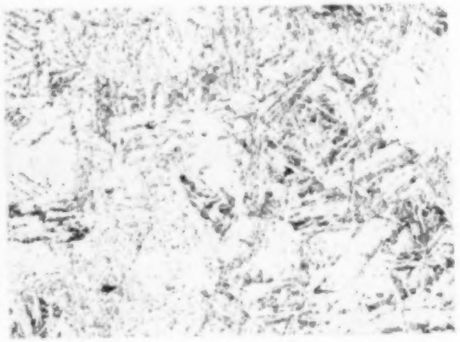
A — Regular Grade × 100 (Etched)

B — 12% Cr-FM With Globular Sulphide Inclusions. × 200 (Unetched)

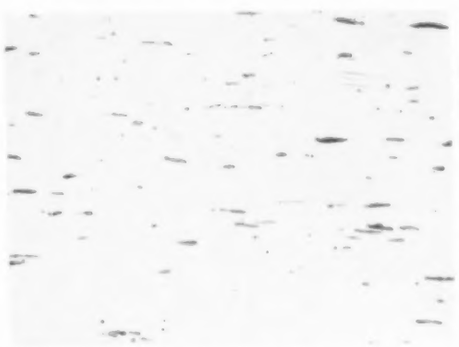


C — Micro B (Etched) × 100. 275 Brinell. Ferrite and martensite plus inclusions

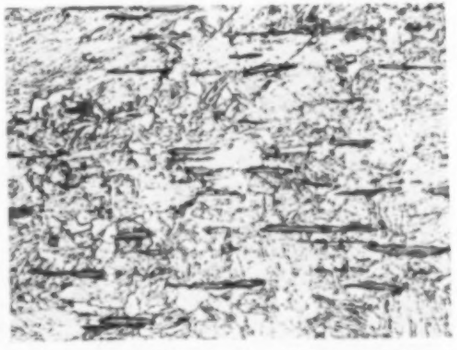
D, E, F, and I Are Wrought 12% Cr Steel



D — Regular Grade × 100. Hardened to 401 Brinell. Martensite (etched)



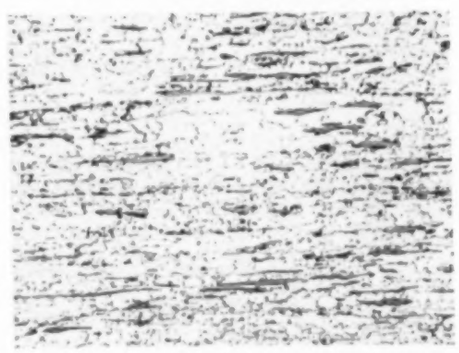
E — 12% Cr-FM With Elongated Sulphide Inclusions. × 100 (Unetched)



F — Micro E (Etched). × 200. Martensite plus sulphide stringers. 375 Brinell

G and H Are Wrought 17% Cr-FM

G — 17% Cr-FM (Unetched) × 200. Showing Elongated Sulphide Particles



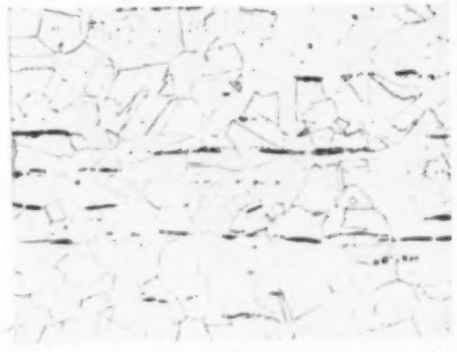
H — Annealed (Etchant: Aqua Regia). Ferrite plus sulphide stringers. 170 Brinell

I — Complex Inclusions in E (× 500). Etchant: Chromic acid

J, K, and L Are Wrought 18-8 Se-FM

J — Duplex Structure of Selenide Particles. × 500 (Unetched)

K — Normal Distribution of Selenides in Annealed Alloy. × 100 (Unetched)



L — Micro K (×200), Etchant: Aqua Regia. Inclusions in austenitic grains. 156 Brinell

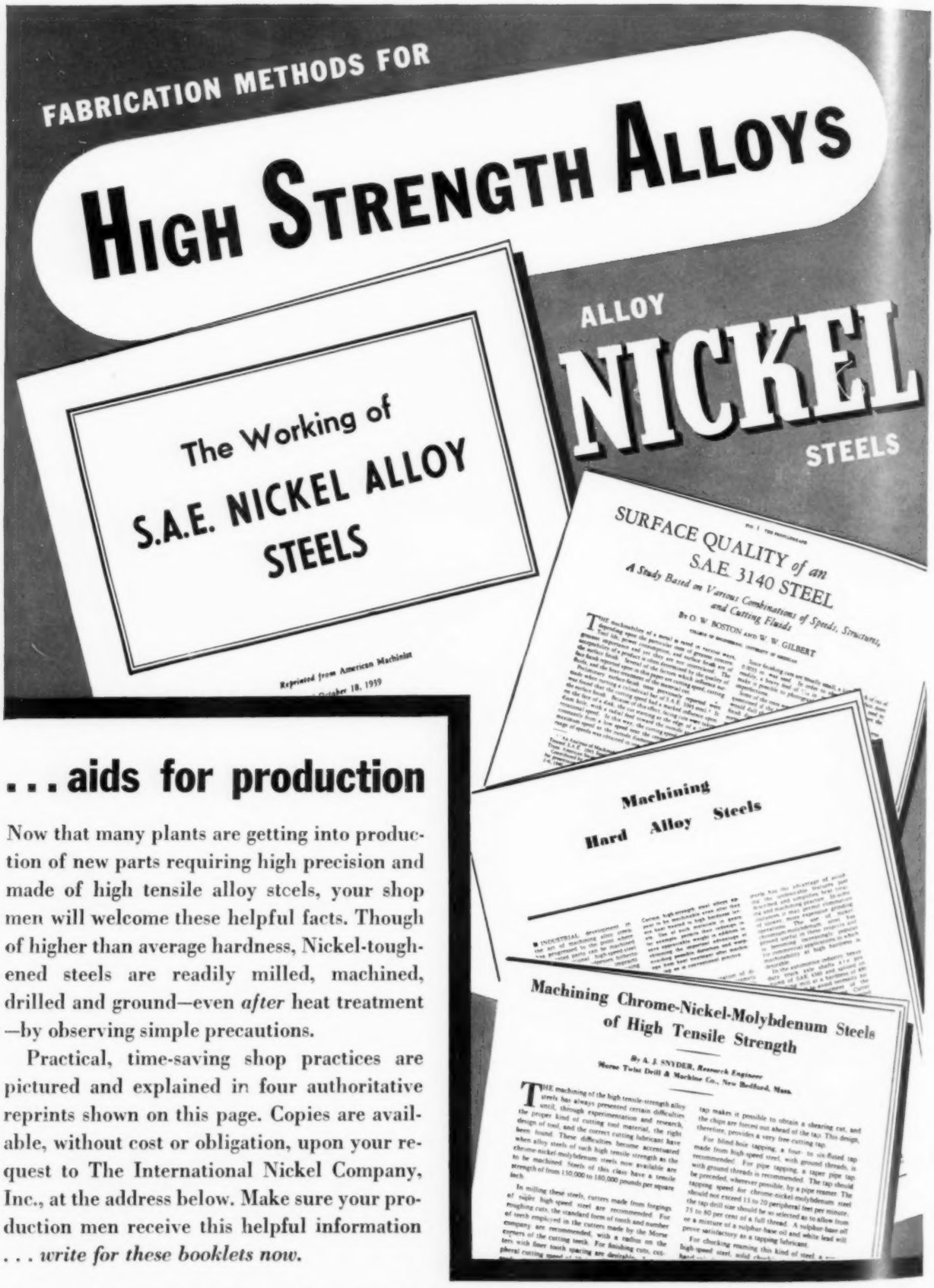
FABRICATION METHODS FOR

HIGH STRENGTH ALLOYS

ALLOY

NICKEL

STEELS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ENOUGH TUNGSTEN for '41

if it is husbanded

By Ernest E. Thum
Editor, Metal Progress
Cleveland

ADDITION OF TUNGSTEN AND TUNGSTEN steels recently to the priorities list has resurrected memories of 1914-1918 when the price of tungsten and high speed toolsteel went up through the roof and eventually had to be put under control. Are we headed toward a similar situation in 1941-42?

As shown by Mr. EMMONS in his article on page 427, the "normal" consumption of tungsten (as measured by total steel ingot production in 1936 to 1939 inclusive) is 0.12 lb. tungsten per ton of steel. Since we made 66,674,000 tons of steel ingots in 1940, this would indicate a requirement of 8,000,000 lb. of tungsten metal. As a matter of fact, the *actual* consumption in 1940 was on the order of 10,000,000 lb. The current ratio, instead of being 0.12, is therefore more like 0.15 lb. tungsten per ton of steel produced. Are we headed for larger ratios like the 0.20, 0.17, 0.33 and 0.28 of the years 1916 to 1919 inclusive?

The justification for measuring tungsten in terms of steel ingots is that 90% of the tungsten is made into metal forming and cutting tools, and that as more steel is made, more tools are required to forge and machine it. Likewise, steel production is an accepted index of general industrial activity — when a lot of steel is made the people of the United States and our foreign customers have money to spend for plows, automobiles and sewing machines, and it requires a proportionate amount of high speed steel cutting tools to make these things.

If an allowance is made for the inevitable tendency to stock up in times of prosperity, and live off the fat in times of depression, the ratio of tungsten tools to steel ingots appears to be slowly rising over the last 30 years, but not at such a rate as to anticipate such a high consumption of tungsten into toolsteels in 1940 as actually occurred. (See the lower curve on page 429.)

The true explanation largely rests on the same circumstances that existed during the last war, when the ratio of consumption shot up to 0.25 lb. tungsten per ton of steel. These are four in number:

First: An unusually large number of new and powerful machine tools are getting into production, frequently into entirely new and specialized plants for aircraft engines, tanks, arms and ammunition. It takes far more high speed steel to fill the tool cribs in these new plants and departments than it does to keep them going, once they are tooled up.

Second: An unusually large proportion of our expanding steel production goes into highly machined parts. Normally we would find that the tonnage of tinplate, rails, fence wire and corrugated iron that requires little or no machining would go up in a prosperous year as fast as the forging billets, castings and other metals that require a lot of turning, drilling and milling before they are salable. In 1941 the tonnage peace-time demands may be expected to be stationary or receding, whereas the amount of steels and alloys for machined parts — highly machined parts — is rapidly expanding.

Third: Machine work on aluminum castings and forgings (and drilling for rivets) requires a disproportionately high amount of high speed steel.

Fourth: The sudden expansion in toolsteel demand correspondingly increases the amount of tungsten apparently consumed but really in process — in transit, being smelted, in steel mill

stockpiles, existing as croppings and mill scrap, in tool makers' bar-stock supplies and on tool jobbers' shelves. This, of course, is a temporary demand; soon the industry becomes balanced in its production at a higher level.

With these items in view, how much tungsten may be needed in 1941, assuming near-capacity operation of our steel industry (84 million tons)? With all due appreciation of the dangers of estimating war-time needs by peace-time records, one might guess as follows:

In 1936 to 1939 we used 0.12 lb. tungsten per ton of steel for pacific purposes.

In 1940, straining to get into armament production, we used 0.15 lb. tungsten per ton of steel.

In 1941 the same increase should be anticipated; we should visualize the need of 0.18 lb. of tungsten for all the steel we can make. 0.18 × 84 million is 15,000,000 lb. of tungsten, half again more than was used in 1940.

Where can we get that much?

We get our tungsten from home and abroad. What is the probability of expanded mine output in the United States?

Our tungsten mines have been reasonably stable in production since 1936, despite rather wide fluctuations in price:

1936	2,486,000 lb. of tungsten
1937	3,331,000
1938	2,897,000
1939	4,080,000

1940 figures for mine shipments are not yet available from the U. S. Bureau of Mines, but may be estimated at 4,500,000 lb. tungsten. Current prices are somewhat "nominal", but at $25.00 per unit of 20 lb. of contained WO_3 ($1.25 a pound of tungsten trioxide or $1.00 per lb. of contained tungsten) are sufficient to encourage a surprising number of small mine owners to equip little concentrators to produce mineral of specified grade (60% WO_3 content or better). The two largest American producing mines — Nevada-Massachusetts Co. and U. S. Vanadium Corp. in Nevada and California respectively — are each actively enlarging their facilities and by fall will be producing from two to three times their present tonnage. During 1941 the trend of production by the little mines certainly will be upward, and the leading producers sharply upward. Confidently we may expect 6500 tons of 60% WO_3 concentrate in 1941, equivalent to 6,200,000 lb. of tungsten. (By the end of the year the production rate should be at least 600,000 lb. of metal per month.)

Now, figuring the 1941 requirements at 15 million and the American production at 6,200,000 lb. of tungsten, that leaves 8,800,000 lb. of metal to be secured from abroad. But first, what of the undeveloped possibilities in our own country?

The U. S. Bureau of Mines and the U. S. Geological Survey have, for nearly two years, been investigating tungsten prospects and mines, big and little, doing enough development work on favorable sites to estimate the potentialities of each. Explorations consist of trenching, diamond drilling and sampling of underground workings. To date, no rich deposit has been discovered, but the unmistakable indications are that we have a *very* large amount of low grade ore. Development of such deposits will require not a temporary higher price, but an assured market long enough and high enough to return the development and plant costs. Fortunately the so-called Strategic Metals Act authorizes the purchase (by the Procurement Division of the Treasury Department) of tungsten at prices and under conditions as to develop necessary American resources.

None of these possibilities, while important to our future resources, can hardly be expected to augment our 1941 supplies. So, as before, we have to find 8,800,000 lb. of tungsten abroad. This is on the order of the amount imported in 1918 and 1919 in the last war, when the roads were open to China, the principal source of the metal. It is also many times the importations of 1939, the last year of published figures.

Data for importations in 1940 have not yet been released for publication, but it may be stated that Argentina, Bolivia, Peru and Mexico expanded their shipments to us sevenfold over 1939, and the 2,500,000 lb. received from them was sufficient (with local mine production) for 70% of our needs last year. Imports from all the rest of the world during 1940 — certainly very large — therefore went, for the most part, into warehouse stocks and government stockpiles.

These imports from the Americas are currently at a still greater rate than the average for 1940, and a conservative supposition will be 3,500,000 lb. of tungsten from these countries to the south of us in 1941. We therefore have

Estimated requirements	15,000,000 lb.
Estimated U.S.A. production	6,200,000 lb.
Estimated production of southern countries	3,500,000 lb.
Apparent deficiency in 1941	5,300,000 lb.

There are three sources from which we may supply the deficiency. First is to draw down the normal stocks in our own ferro-alloy industry (normally three or four months' supply). A second is by releasing tungsten from the mounting stockpile owned by the Procurement Division of the Treasury. This can lawfully be done only for defense requirements. Third is by using the imports from the other hemisphere, principally China and Portugal (Australia and South Africa will doubtless ship to England). At present the difficulty is more in getting ships to carry this ore than to collect it at foreign ports ready for shipment. 33,000 tons of it (31,000,000 lb. of tungsten — two years' supply) is already purchased, according to JESSE JONES' statement on Feb. 22, in reporting on the activities of the Metals Reserve Co. At that time 850,000 lb. of this metal was reported as "afloat". Actual arrivals at U. S. ports in the first three months of this year from sources outside this hemisphere have been at a rate sufficient to cover the apparent deficiency and leave a comfortable surplus.

Now it may be asked, "Can we smelt this amount of ore; convert it into ferrotungsten or into the compounds useful for direct furnace additions?" The answer is yes. The two firms that handle almost all of this business have successfully taken care of the doubled requirements in 1940. Further necessary expansions are under way. The methods and equipment are not too complicated nor expensive.

All things considered, there will in all probability be enough tungsten delivered during 1941 for the actual requirements. 90% of it will be used in alloy steel, principally high speed toolsteel. So much of it will be government-controlled and earmarked for defense that there will be none of it left over to build up *private* manufacturers' stocks, either of ore, ferrotungsten, or tungsten steels. In fact, the priorities now in force will see to it that defense industries have first call and will get all the high speed steel they need. Industries serving civilians will have to conserve what tools they now have on hand and for many purposes may quite properly be required to buy cutting tools that use less tungsten — either a carbon toolsteel, a low tungsten steel, a molybdenum-tungsten steel, inserts of cemented carbides or a low tungsten stellite. Fortunately, when any of these tool materials are properly applied, they give outstanding performances. They merely need intelligent selection, treatment and application.

OPENHEARTH
design and practice

By William C. Buell, Jr.

Extracts from article in Iron and Steel Engineer, *March 1941, page 28*

IN AN ATTEMPT TO EVALUATE AMERICAN basic practice, a large number of operating records were collected from 35 steel producers, representing four-fifths of our ingot capacity. Sufficient information about 21 plants is available, ranging from data about a single campaign of a single furnace to summaries of an entire plant for a year, to make some interesting general conclusions, as set forth in what follows.

Openhearth steel making (ingot cost) is affected by four cardinal items, each one of which has secondary divisions, as follows: A. The Furnace; B. The Plant Layout; C. The Iron and Raw Material Supply; D. The Personnel. All these (and their secondary factors) must be coordinated to the highest degree to achieve better than average costs.

Let us first examine what the available figures say about various factors of furnace design.

Bath Depth — It would seem that the capacity of the openhearth bath (the metal volume actually contained) has little or no effect on the quality of the steel made therein. In the great majority of the hot metal plants, steel is usually made in furnaces tapping from 125 to about 200 tons. Furnaces approaching the latter capacity appear to offer the optimum economic practice. Various delays in charging and teeming, and difficulties with soaking pit and blooming mill schedules are apt to nullify the advantages of the larger furnace units. Today hearths are seldom more than 36 in. deep; if satisfactory steel is made in the deeper baths an unduly long processing time is required.

Production Rates — Time of heats and rates of production are interrelated. As a unit of comparative production rate and over-all operating effects, we have chosen the value P, meaning "production of steel in net tons per hr., per 1000 cu.ft. of metal volume being tapped".

This places the results of the operation of all furnaces, no matter what their size, on a directly comparable plane. Further, this rating is founded on the metal actually tapped into the ladle, the only really accurate value of steel making practice. Using now for T, the time of heat from charge to tap, it is easily *(Cont. on page 482)*

SELECTION OF STEELS

as affected by endurance limit

By Gordon T. Williams
Metallurgist
Deere & Company
Moline, Ill.

IN THE FIRST ARTICLE OF WHAT MAY BE a series (March 1941 METAL PROGRESS) the tensile test was discussed somewhat informally, and the conclusion reached that it is very useful to compare one order of metal with another that had proven satisfactory in a given service. While the elements of mechanical design are based on tensile and shear strengths, the actual stresses in a part in service are so complex, and the designer usually provides so much extra metal that it very rarely fails from being pulled or torn apart. Most machinery wears out. Most of the rest of the failures come from "fatigue" of the metal, and that is what this article will now discuss.

"Fatigue." Metal does not get tired, but something happens inside — what it is, we do not know. "Fatigue failure" means failure of material after repeated application of a load that it will safely stand in one application. After all, it seems surprising that a hardened steel specimen, which will carry 215,000 psi. in a tension test without showing any plastic deformation, will break by the application of 120,000 psi. if repeated often enough. The endurance strength (that is, the load that can be withstood for an infinite number of repetitions) is ordinarily but not necessarily below the yield point and is close to 50% of the tensile strength.

A fatigue testing machine is a simple looking affair; eight or ten of them can be placed on a table. The most used specimen is shown in Fig. 1. Each end is carried in a long bearing and each bearing is swivelled so that weights hung on each will load the specimen as a beam — that is, compression on the top elements, tension on the bottom. A small motor now rotates this specimen rapidly, and it is evident that each element goes through a complete cycle from compression to tension and back again during each rotation. Also that the maximum stresses will occur on the surface at the reduced portion of the test piece.

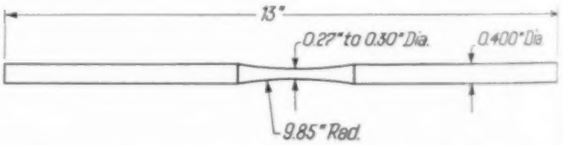

Fig. 1 — Specimen for Determining Endurance Limit of Strong Metal in a "Rotating Beam" Machine

This testing is not to be undertaken lightly. It takes dozens of specimens to establish fatigue characteristics, specimens which are expensive and have to be run literally for millions of cycles. Examine Fig. 2, the curve plotting the results of a series of such tests. The horizontal scale is logarithmic, so that 100 million cycles can be plotted on something less than a roll of wall paper. We find if the specimen is run at a load of 63,000 psi. for about 40,000 cycles, it breaks. When putting on 60,000 psi. it did not break until 10^5 or 100,000 cycles. We found that

when it put on 55,000 psi. for 400,000 cycles it broke. Similarly, we got up to about 2,000,000 applications (10^6) at about 52,000 psi. before it broke. Decreasing the load, we find that we can apply load of 48,500 psi. for an indefinite number of cycles.

Note that this is a nickel-chromium steel annealed dead soft (by furnace cooling) to 87,300 psi. tensile strength. In a single "pull test" it did not break until the load reached 87,300 psi. However it broke in a "push-pull" test, repeated 2 million times between 50,000 psi. tension and 50,000 psi. compression!

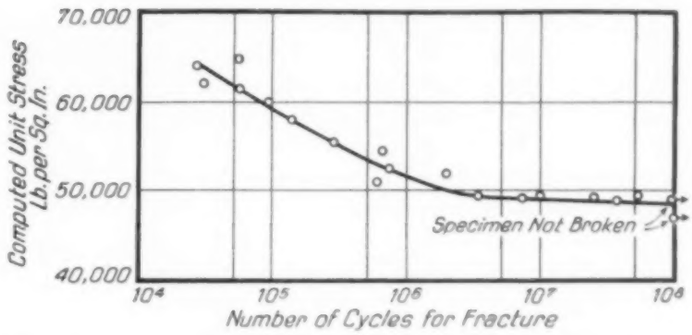

Fig. 2 — Relation Between Stress and Number of Applications for Failure ("S-N Diagram") for a Steel Having 3.3% Ni, 0.9% Cr and 0.25% C, Furnace Annealed to 87,300 Psi. Tests made in dry air at room temperature by Moore and Jasper

Bolts made of a similar material — whose endurance limit as determined on polished normal specimens was 51,000 psi. — are of particular interest to aircraft engine builders, so a number of ¼-in. specimens were machined with 28 threads per in. Tests were run, the available area figured at the root of the thread, and results plotted in Fig. 3. Notice what happened: Simply having those spiral ridges has cut endurance limit, and the load that can be carried through an indefinite number of cycles is down to about 43,000 psi. A coarser thread on a larger root cuts it down to about 37,000 psi. The thread, however, is very much stronger than a series of plain grooves. The results show that a ⅜-in. diameter round with 24 grooves per in. has an endurance limit of only 21,000 psi., and a ¼-in. round with 28 similar grooves stands but 12,000.

Here is a good steel, worth 51,000 psi. in normal fatigue, whose resistance has been cut to 12,000 psi. by grooves. This is a perfect example of the damage from surface irregularities!

Figure 4 (page 465) shows another thing we must worry about. If specimens or the actual parts on which we run fatigue tests are highly polished, we will get value for endurance limit that is called 100%. It will be roughly 50% of the tensile strength, regardless of whether the tensile strength is 40,000 or 220,000 psi. If samples are normally polished instead of mirror polished, we get nearly 100% of full endurance limit on the weaker material, but as we improve the tensile strength of the steel by heat treatment, the effect of the slight roughness is to cut the endurance limit to 85% of the perfect condition. Machining marks on the higher strength material damage it even more — down to 70%.

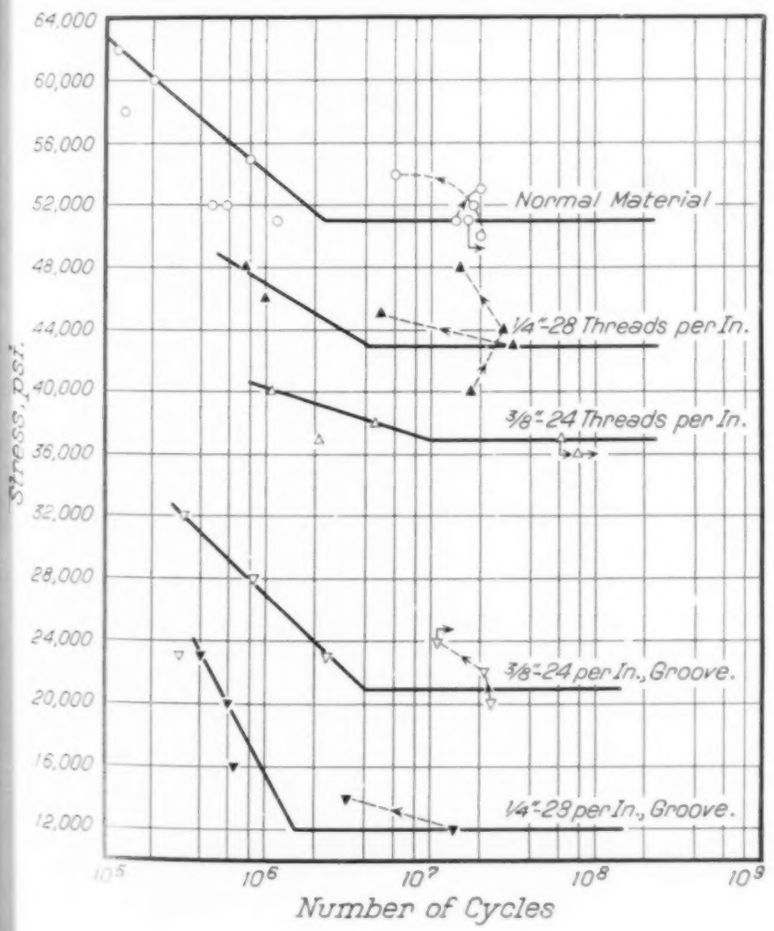

Fig. 3 — Effect of Size of Specimen and Number of Threads per In. on Endurance of Heat Treated Alloy Steel Rounds With Normal Endurance Limit of 51,000 Psi.

With a circular notch, the high strength material takes what might be called an awful licking. If soft steel (with a tensile strength of 50,000 psi. and an endurance limit of 25,000) has a circular notch its endurance limit may be expected to be 85% of "normal" or 21,000 psi. However a hardened steel of 210,000 psi. would have its "normal" endurance limit of 105,000 psi. cut to 40% of what a smooth specimen would give — that is, the endurance limit is now 42,000 psi. It is at the same time very interesting to notice that mill scale is even more damaging than a sharp circular notch; strangely enough tap water is quite damaging; salt water even more so.

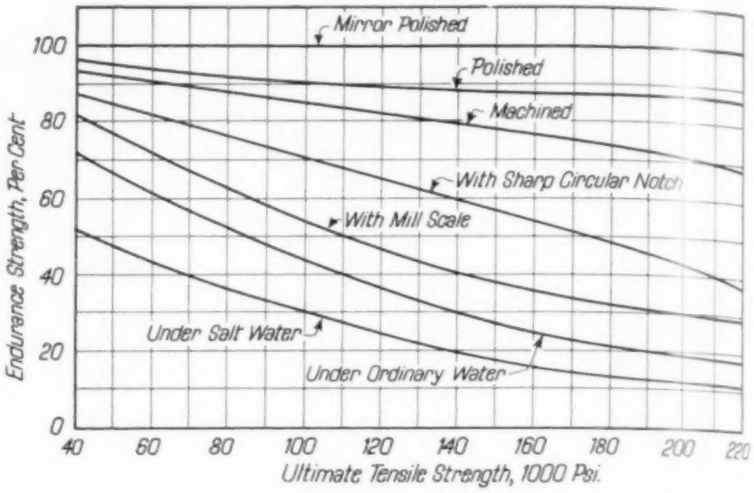

Fig. 4 — Best Results in Endurance Tests Come From Mirror Polished Specimens Run in Dry Air. Rough surfaces, notches and corrosive surroundings reduce the fatigue limit, especially of heat treated steels (Karpor, "Metals & Alloys", Dec., 1939)

Don't forget that the higher strength material is more sensitive to notches or damage of any sort.

Note the serious trouble from corrosion. Running tap water will reduce the endurance limit of the strongest steel to that of wrought iron. Hence the necessity for using high copper alloys, bronzes, monel and stainless steel in corrosive surroundings. The *surface*, that carries the highest loads, must not be notched by chemical attack.

The question is asked about the relation of heat to the endurance limit. This reduces more to a consideration of the effect of heat on the corrosive attack by the metal's surroundings than to the effect of heat on the metal's inherent fatigue resistance. Extensive tests, for instance, have been made on the endurance of turbine blades in superheated steam, but the main requirement is non-corrodibility.

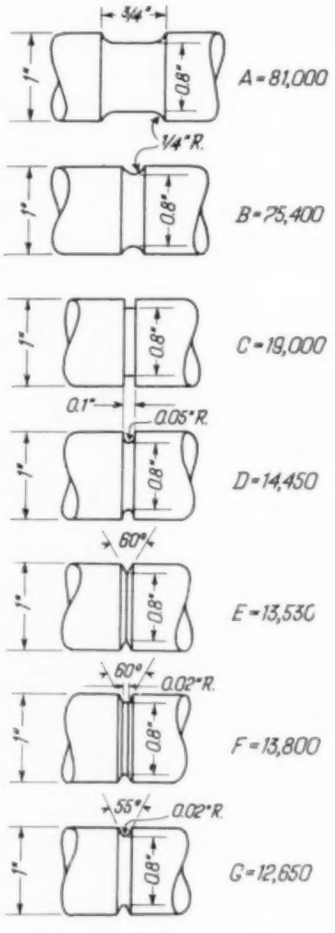

Fig. 5 — Shape of Notch Has Pronounced Effect on Number of Load Repetitions to Failure

Avoid Sharp Notches

Shape of the notch also has an important effect. F. F. JOHNSON of Spencer Mfg. Co. has reported a notable series of informative tests in *Automotive Industries*, Nov. 22, 1934, and Fig. 5 summarizes his results. He took a 1-in. bar of SAE 3140 and heat treated it to Brinell 321. In this condition it had a tensile strength of about 150,000 psi. and its endurance limit would be about 75,000 psi. He then carefully cut different shaped notches of equal depth in seven pieces, and put them in a rotating beam machine, so loaded that the computed stress at the base of the notch was 77,000 psi. A smooth bar tested under these conditions would run to millions of stressings before it would break, if at all. Note what actually happened:

A: A nice fillet ran for 81,000 revolutions.

B: A liberal fillet — not as liberal as A — 75,400.

C: A sharp square groove, 19,000.

D: 14,450. (Frankly, I think that perhaps re-running of these tests might show that *C* landed out of place — a sharp groove should be a more damaging notch than the rounded one *D*.)

E: A very sharp notch broke after 13,530 loadings (revolutions).

G: A moderately sharp notch. 12,650.

Notice by manipulating size of grooves, we have dropped all the way from 81,000 revolutions to 12,650 revolutions before failure.

We have cited so many cases where the endurance limit of a metal may be damaged (and the end is not yet) that it may be well to say something about what can be done to *improve* the endurance. (Of course we can *maintain* the inherent capacity of metal by favorable shape and protection from corrosion.)

We have already seen that failure by alternating stress (fatigue) is greatly accelerated in corrosive surroundings if the nature of the alternating stress puts *tension* on the surface. On the other hand, corrosion is innocuous if the surface is merely under fluctuating compressive loads. It is almost as though the corrosion penetrates into regions where the atoms are stretched apart slightly — into something like tiny cracks — whereas the attacking corrosive substances are repelled when the metal atoms are always squeezed together somewhat. However that may be, the practical aspect is this: If a properly made axle, piston rod or propeller blade is finally burnished by pressure rollers, a thin surface layer of metal is put in a condition of strong compression, so great in intensity that the loads of service never stress the pre-stressed surface beyond zero to tension, and life and resistance to fatigue in atmospheric, steam and oil corrosion are greatly enhanced.

Decarburization can knock down the endurance limit, the same as machining defects can.

Figure 6 shows results of effect of decarburized surfaces on the fatigue strength of carbon and alloy steels. Again we see the higher the strength of material, the more sensitive it is to damage. If steel has a tensile strength of 60,000 psi., it doesn't matter whether it is decarburized or not, because decarburized steel (soft steel) will have a strength of 60,000 psi. That is as good as the steel itself. Notice on 200,000-lb. steel, where we can get a fatigue strength of 105,000 psi. without decarburization, it drops down to 50,000 if decarburized in heat treatment. This has nothing to do with loss in *size*. These samples were decarburized in a way that gave no size change.

A good example is a splined shaft, decarburized in heat treatment. Afterwards the shop carefully grinds the shaft without touching the groove. The groove is where the crack will start anyhow, and if the decarburization is still there, the damage is accentuated.

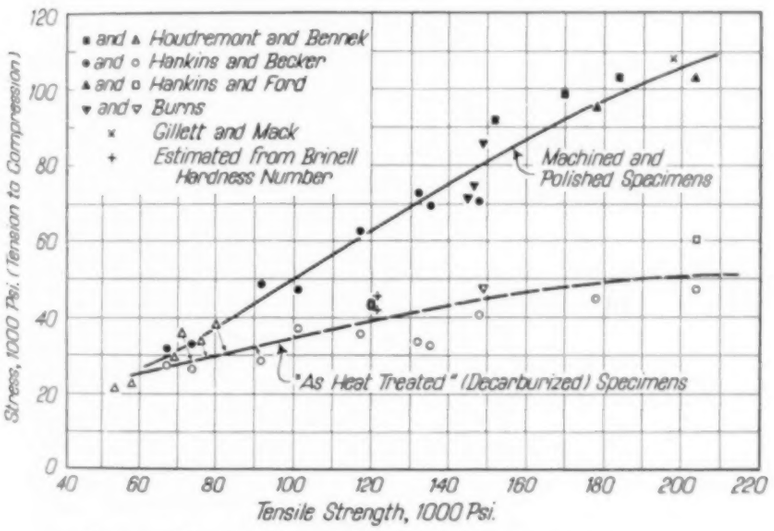

Fig. 6 — Effect of Decarburized Surfaces on Fatigue Strength of Carbon and Alloy Steels (Rotating Beam Type of Testing Machine). Data collected by R. W. Clyne

Decarburization is also a very potent factor in the life and serviceability of leaf springs. The automotive industry has made tremendous strides in improving quality of springs by watching for surface defects and decarburization, going to the limit of grinding the flats. Valve springs also suffer badly from decarburization during improper heat treatment.

Mention of springs brings up the problem of full-sized tests. The problem of translating information derived from relatively small laboratory pieces into knowledge about the probable action of relatively huge machine or structural parts in service, is a problem that faces every materials man and designer — especially now, when scale-model tests are fashionable.

This "scale" or "proportionality" effect leads to some disquieting doubts when one reads Oscar Horger's article on engine axles in Metal Progress, February issue. Made of 0.45% carbon steel and tested (either as forged, or subsequently normalized) the endurance limit of emery-finished, rotating beam specimens up to 2 in. in diameter is about 31,000 psi. — a rather low figure for a 90,000-lb. tensile steel — but only 17,500 psi. on "smooth turned" 6-in. diameter

specimens. Likewise, when a wheel is pressed on the end of these full-sized axles and the assembly tested, cracks will start at alternating stresses of 9000 to 13,500 psi., but the cracks do not progress and cause failure until the stress is increased 2500 psi. in each case.

There are a lot of unexplainable things in these tests, and they are mentioned here merely to show that mass as well as *time* is an important thing to consider when investigating fatigue failures—or better, when arranging to avoid them. They also prove the logic of full-sized tests of automotive axle shafts in alternating torsion, since it is evidently impossible to translate test results from polished samples because of the different nature of the stresses (torsion instead of bending), the questionable stresses due to tapered shaft and flanged or splined ends, and the non-uniform hardness (strength) surface-to-axis after heat treatment.

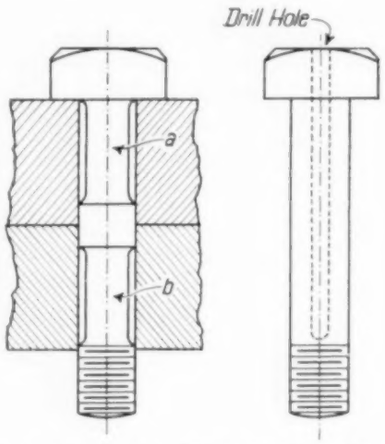

Fig. 7 — Bolts Strengthened Against Fatigue Under Repeated Shock by Removing Metal. (Fairlie)

We have noticed how notches act as stress raisers. Also, please note that a notch does not have to go *in*; the part sticking out beyond the notch is the part that has done the damage! It has been found that if you take a 1-in. diameter shaft and find it has a certain endurance limit, and then turn a 1-in. shaft out of a 2-in. bar of the same steel but leave a ring that is 2 in. dia. in the center, it will break every time at the shoulder. It is a stress raiser. Shrunk-on parts, such as ball-bearing races and car wheels, act as stress raisers. HORGER's researches at Timken Roller Bearing Co. mentioned above found that you can damage a shaft by shrinking on a wheel as much as by sharp grooving. He has also found how to increase the fatigue strength of a railroad car axle by 80%, principally by changing the shape and size at and near the wheel seat. The better axle is only 4% heavier.

Another example of sound reasoning in design, to get away from notch effects, is shown in Fig. 7. Bolts may be strengthened by *removing* material. We may reduce the shank of the bolt so that it can deform elastically; portions *a* and *b* take up the shock. In another case, since the weakest point is in the threads, drill a hole down the center of the shank only (not the threaded section). This reduces the load carrying characteristics so that the shank is weaker and the bolt as a whole is stronger, for it is free to "come and go" so that the load is not concentrated on the weakest point in the threads.

Similar conditions to bolt threads exist at the roots of gear teeth and shaft splines. Figure 8 represents findings reported in *Automotive Industries*, Nov. 15, 1940, by GUSTAF CARVELLI. The stress concentration factor for a normal gear-tooth is 3.5. There is a series of right angles cut as the hob or other generating tool goes around. With that kind of root "radius", the stress concentration at that particular point is 3.5 times what it would have been in solid material unaffected by such grooves.

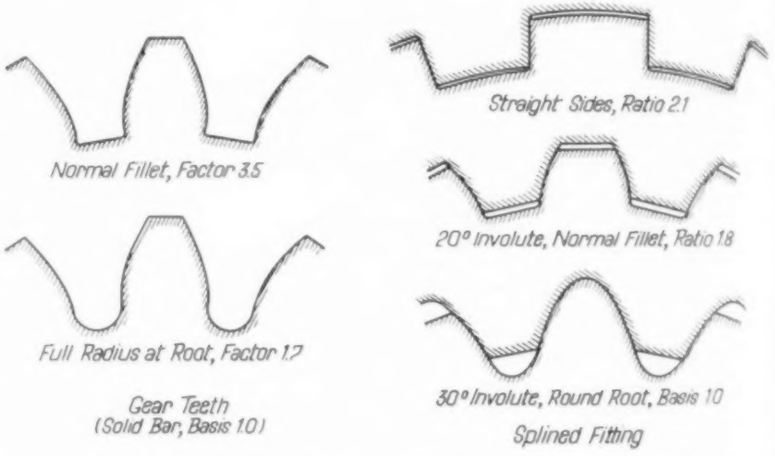
Normal Fillet, Factor 3.5
Straight Sides, Ratio 2.1
20° Involute, Normal Fillet, Ratio 1.8
Full Radius at Root, Factor 1.7
30° Involute, Round Root, Basis 1.0
Gear Teeth
(Solid Bar, Basis 1.0)
Splined Fitting

Fig. 8 — Factors and Ratios Whereby Various Designs of Gears and Splines May Be Evaluated, as to Their Fatigue Resistance

If a good liberal radius is put in the bottom of the teeth, the stress concentration is only 1.7. In other words, the teeth with round bottoms are exactly double as good as the usual teeth—same material, with same heat treatment.

The same remarks apply to splines. At the top of Fig. 8 is an ordinary square shoulder type of spline. We set up a stress 2.1 times what it would be without *(Cont. on p. 508)*

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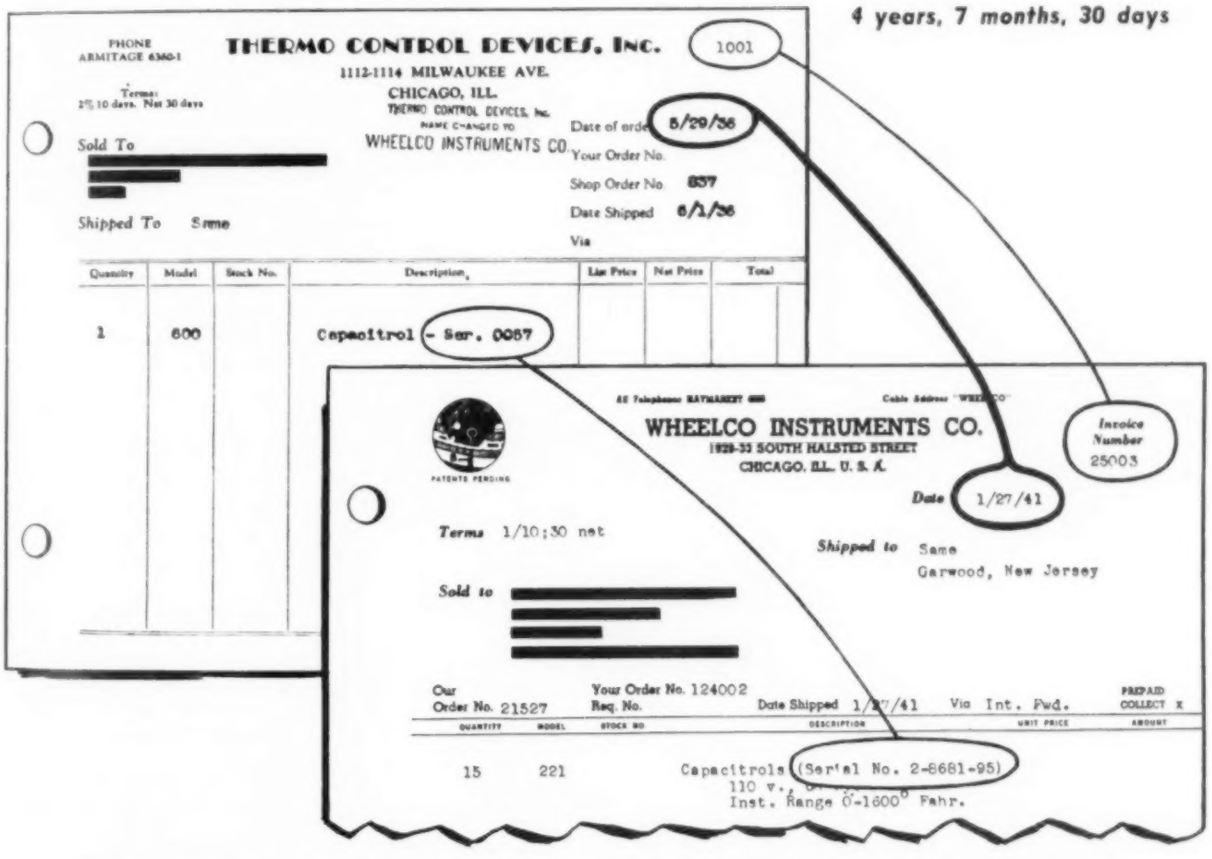

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PERSONALS

Henry D. Bechtel, formerly with Ohio Brass Co., Mansfield, Ohio, is now with the Foundry Equipment Co., Cleveland.

W. L. Havekotte has left American Rolling Mill Co., to join the staff of Battelle Memorial Institute, Columbus, Ohio, as research engineer.

John P. Clark, formerly representative of Minneapolis-Honeywell Regulator Co. in Cleveland, is now metallurgical sales engineer in New York City, New Jersey and Eastern Pennsylvania for Park Chemical Co. of Detroit. **Frank J. Staral**, formerly with Steel & Tubes Co., is now representing Park Chemical Co. in the Indiana and Kentucky territory, with headquarters at Indianapolis.

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Harry E. Orr, chief metallurgist of Burnside Steel Foundry Co., has been appointed sales engineer for Vanadium Corp. of America with headquarters in Chicago.

Promoted by The Bullard Co.: **Foster P. Whitworth,** from assistant works manager to works manager.

Raymond E. Christie, previously assistant to the president, has been elected vice-president and director of the Crucible Steel Co. of America.

Max E. Tatman is now metallurgist for the Consolidated Aircraft Corp., San Diego, Calif.

H. L. Nicholson is in the metallurgical department of Ohio Seamless Tube Co., Shelby, Ohio.

G. E. Guellich, formerly with the George Scherr Co., is now metallurgist of Spencer Lens Co., Research Division, Buffalo.

M. J. Wahll, formerly employed by Deere & Co., is now a metallurgical inspector at the Chicago Ordnance Division.

Norman H. Davies, sales engineer, the North American Mfg. Co., has been transferred from the Chicago office to the main office in Cleveland.

R. A. H. Galbraith is now a lieutenant colonel associated with the Inspection Board of the United Kingdom and Canada, located in Ottawa, Canada.

Paul D. Strubhar, formerly with Ingersoll-Rand Co., is now employed by Hyatt Roller Bearing Division, General Motors Corp., Harrison, N. J.

Robert R. Allen is now working for Wright Aeronautical Corp., Paterson, N. J.

Richard B. Kropf, formerly field metallurgist, Chicago District, Republic Steel Corp., now has a similar position with Copperweld Steel Co. in Warren, Ohio.

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PERSONALS

Charles H. Hoefer, formerly superintendent of the alloy division, Lebanon Steel Foundry, has been made general superintendent of the Duraloy Co., Scottdale, Pa. **Harvey T. Harrison,** general sales manager for Duraloy, has been elected vice-president in charge of sales.

Harry J. Heuster, for 20 years in the Equipment and Materials Section of the Bureau of Aeronautics, Navy Department, is now with Reynolds Metals Co. with headquarters in Washington, D. C.

W. H. Steinkamp has been transferred to Pittsburgh, where he will be industrial manager of the Brown Instrument Division of Minneapolis-Honeywell Regulator Co.

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Jack H. Schaum, formerly with Lewis Foundry & Machine Co., is now in the research department of Babcock & Wilcox Co., Barberton, Ohio.

Charles C. Posner has resigned as metallurgist with the Federal Screw Co., Detroit, to accept a position as heat treat foreman, Saginaw Steering Gear Division, General Motors Corp., Saginaw, Mich.

William W. Britton has been made special representative for the Pacific Coast territory by Jessop Steel Co. of Washington, Pa., with headquarters in Los Angeles.

Evan F. Wilson, formerly metallurgical engineer, has been made chief metallurgist and assistant to **H. J. Kerr,** executive assistant of the Babcock & Wilcox Co., Barberton, Ohio.

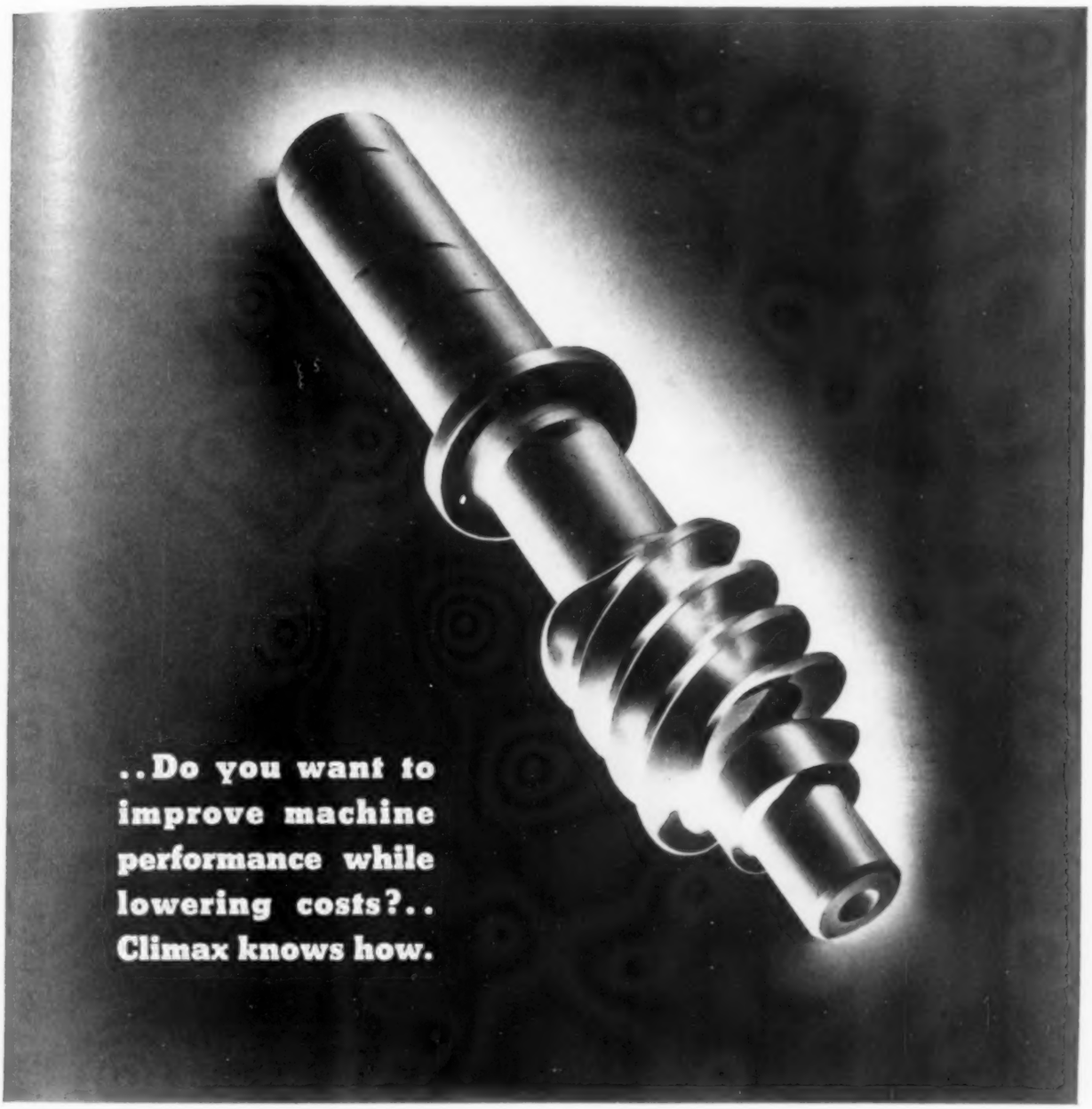
Myles Morgan, assistant chief engineer, Morgan Construction Co., Worcester, Mass., has been made a vice-president of the company.

Roy M. Erlandson, formerly a heat treater for Bausch & Lomb Optical Co., Rochester, N. Y., is now a student in the metallurgy department, University of Kentucky.

R. A. A. Hentschel has been made assistant manager of research in charge of the research work at the Ilion plant of Remington Arms Co., Inc., Ilion, N. Y.

George Van Deventer has been transferred from the Cleveland to the Toledo sales office of the Allegheny Ludlum Steel Corp.

Zay Jeffries, past president and consulting engineer, lamp department, General Electric Co., has been appointed chairman, and **William H. Eisenman,** national secretary, has been named secretary of a special committee of the National Academy of Sciences, to investigate substitutes for aluminum and other defense metals, by the Office of Production Management.



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MOLY

STORAGE of SOFT DURALUMIN BEFORE PRESSING

By J. C. Arrowsmith and K. J. B. Wolfe

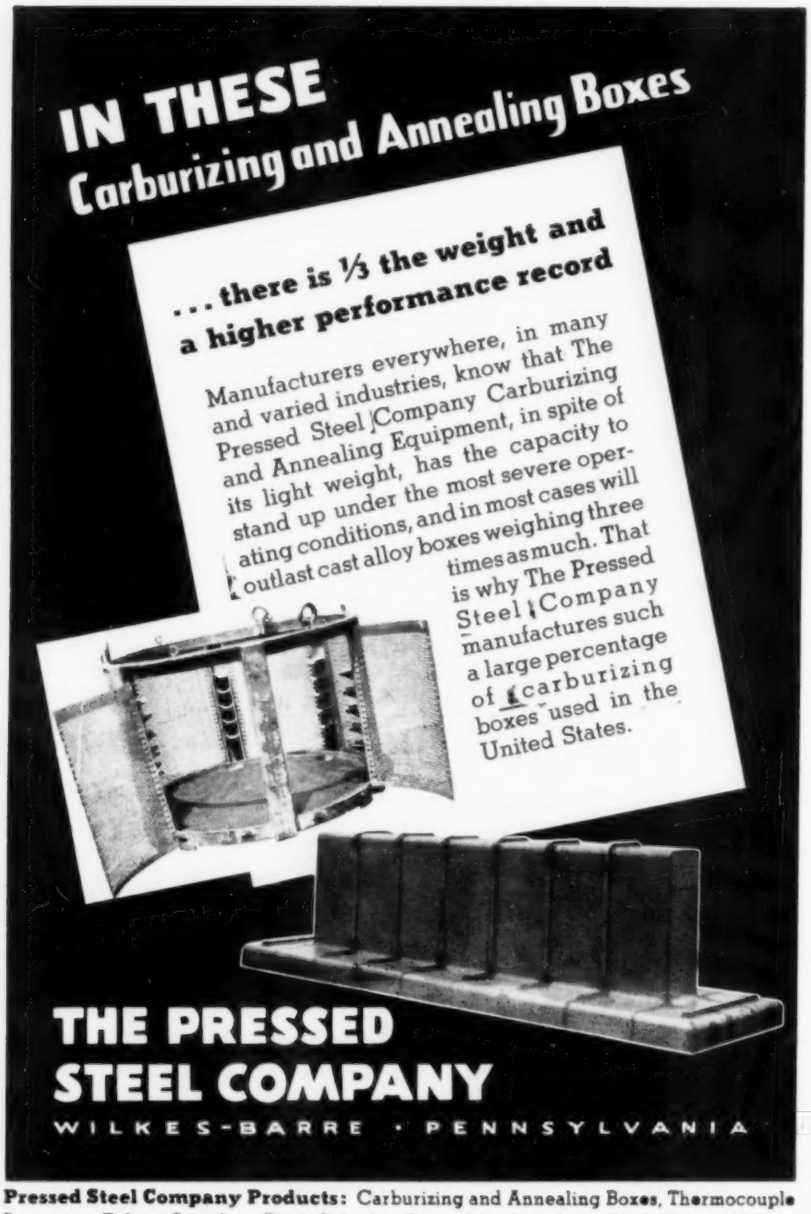
Abstract of Paper 872, Institute of Metals, 1940, entitled "The Use of Refrigeration for Delaying the Age-Hardening of Duralumin-Type Alloys, With Special Reference to the Production of Large Pressings for Aircraft"

Due to the rapid change in ductility of duralumin-type alloys after solution treatment, any operations involving bending or stretching must be carried out within a short time. Where this is impossible, it has been necessary to re-treat the metal. If a large number of parts are involved the second heat treatment hinders production. One of the largest problems, therefore, is the supply of a correct flow of freshly solution-treated blanks at the presses. The length of time that may elapse between solution treatment and the pressing operation varies with the severity of the pressing, and while 2 hr. may be regarded as the maximum permissible for a fairly easy part, a marked increase in tendency to fracture in the more difficult shapes is observed after half an hour.

Recent developments in the aircraft industry have made it essential to reconsider the possibilities of low temperature storage of duralumin after solution treatment. The main object of the authors' investigation was to determine the *maximum* temperature at which a desired increase in permissible storage time could be obtained. Sheets of duralumin (British standard specification 4L3) were tested at various temperatures between 73° and 0° F. The metal contained 4% Cu, 0.53% Mn, 0.50% Mg, 0.38% Si and 0.50% Fe.

The results indicate that there is always a certain interval immediately after the normalizing quench in which practically no change in hardness takes place, the period of delay being greater when the age hardening temperature is lowered. After the period of delay, age hardening proceeds at a rate related to the temperature of storage, the rate decreasing considerably as the maximum degree of hardening is approached.

The effect of decreasing the temperature of aging is very pronounced and it is found that, when the temperature has been reduced to 12° F., the time required for age hardening to reach the value at which it interferes with press work has been extended to a matter of weeks. The most useful and economical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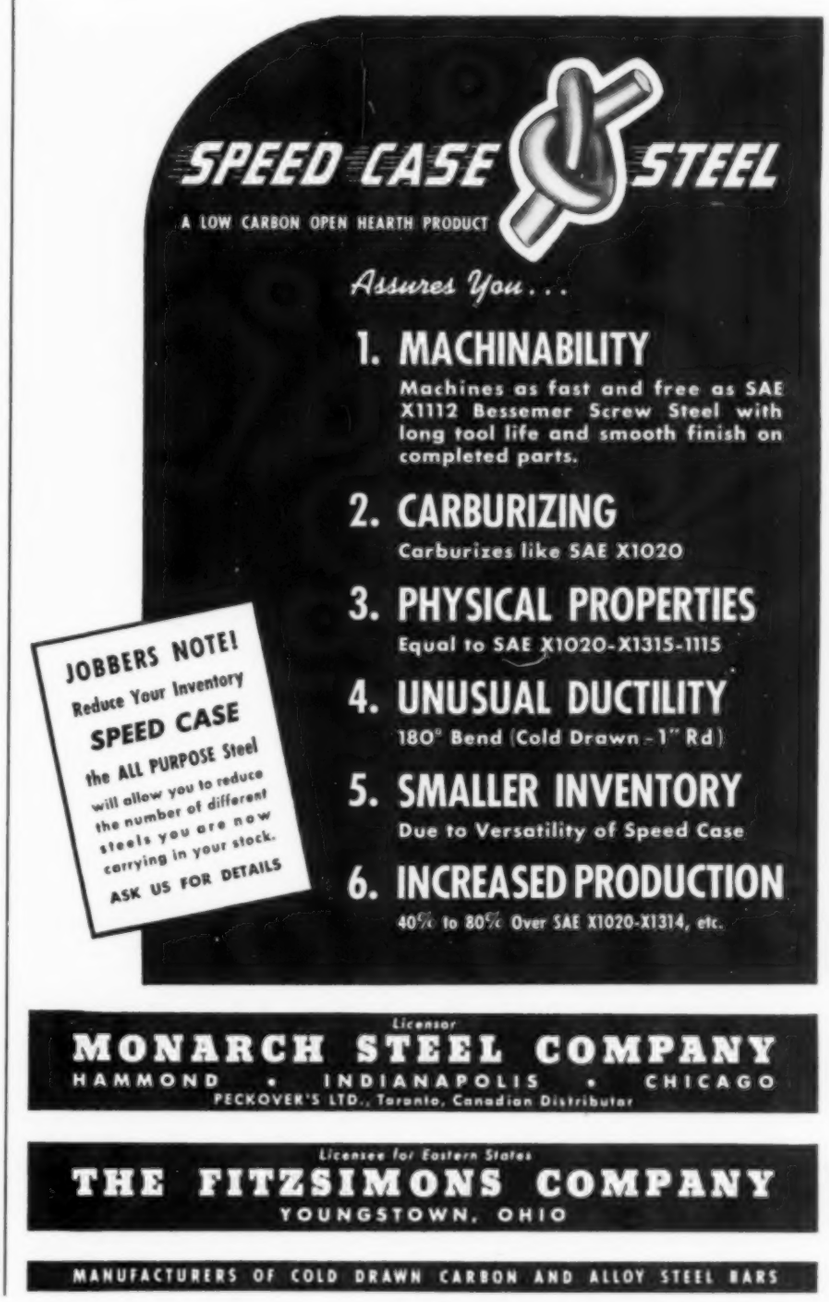
temperature for the storage of heat treated blanks is 15 to 20° F. The limiting aging period would then be about 100 hr. and no appreciable age hardening would occur in the initial 50 hr. of storage.

In constructing a refrigerator for duralumin blanks it was realized that bright sheet metal blanks at the temperature of the water used for quenching after normalizing might take some considerable time to assume the temperature of the air in a refrigerated chamber. During this time the age hardening effects corresponding to the intermediate temperatures would be taking place, which would bring about a reduction in the limiting aging period at the temperature of the refrigerator. (It was found that alclad sheets took twice as long to cool as duralumin, a fact attributed to their more highly polished surface.)

It was therefore decided to build inside the refrigerator a liquid quench bath held at the same temperature as, or slightly lower than, the air temperature of the refrigerator. The freshly normalized (cool) blanks would be immediately immersed in this tank, where they would practically instantaneously be chilled to the temperature of the surrounding liquid, after which they would be removed and placed in storage racks in the main body of the refrigerator. Paraffin was chosen as the liquid to be used in this bath on account of low cost and the fact that the film remaining on the blanks helped to spread the lubricant used in the subsequent pressing operation. Where the presence of paraffin might be undesirable, as, for example, on rivets for an assembly requiring painting, industrial wood alcohol or mineral spirits may be substituted.

A refrigerator incorporating the above refinements was erected immediately outside the salt bath shop so as to avoid any delay between the rinsing of the blanks following the normalizing operation, and low temperature storage. Rapid transfer into the refrigerator, together with the quench into refrigerated paraffin, are both important factors in the delay of age hardening.

Normalized duralumin sheet blanks can be stored at 15 to 20° F. for periods up to four days without age hardening taking place to such an extent as to interfere with cold pressing operations. The use of such a refrigerator in conjunction with the heat treatment department materially increases press efficiency by eliminating the delays which otherwise would occur when waiting for freshly heat treated blanks. Fewer heat treatment furnaces are required because of the more regular flow of work. Finally, the amount of scrap due to cracked or split pressings has been reduced.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MICRO-FISSURES in HEAVY WELDS

By John L. Miller and Lewis R. Kovac

(Abstracted from Welding Research Supplement, February 1941, page 114-S)

The presence of the conical cavities known as "fish-eyes" in test specimens made of all-weld-metal, lowers the tensile strength and adversely affects the ductility, especially as measured in terms of elongation. The authors have attempted to find the cause of the micro-fissures (found at the root of these conical cavities) in multi-bead welds of mild steel, and to determine the effect of various heat treatments upon them. Multi-bead, low carbon steel, metal-arc fusion welds 1 in., 1¼ in., and 2 in. in thickness were prepared and examined.

Two sets of welds were made, Set *A* using the standard welding rod and Set *B* using a special rod of high manganese content. Half of Set *A* was welded continuously and as rapidly as possible at temperatures varying from 0° F. to 20° F. No fissures were found in these plates.

With the rest of Set *A* the entire assembly was cooled before each succeeding bead was deposited. Fissures appeared in these plates in the recrystallized zone of the weld metal. They terminated at the line of demarcation between the coarse-grained and the recrystallized zones and tapered off into the fine-grained weld metal. The greatest width of the micro-fissures is usually adjacent to the coarse-grained metal of the bead that produced recrystallization in the bead or run just below, and leads to the belief that this was the first part to be formed.

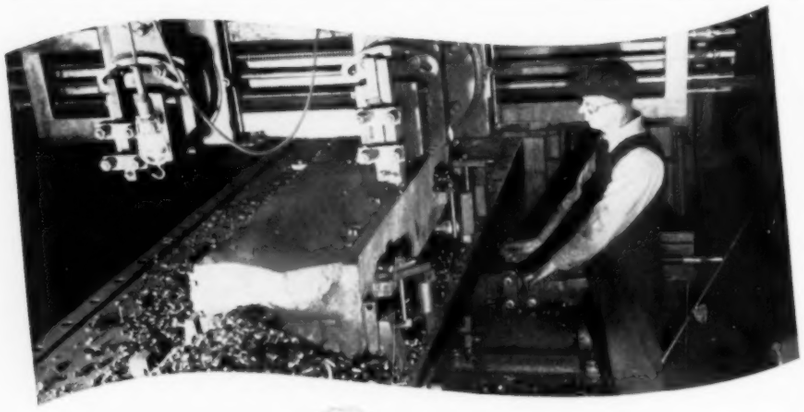
The forces initiating a fissure propagated it, in the manner of a wedge, downward into the weld during the progress of recrystallization. Perhaps the recrystallization, occurring at a temperature where cohesive strength of the grain boundaries was low, produced intercrystalline fractures.

The plate welded at 70° F., however, had but few fissures. The use of a higher manganese content in the welding rod in Set *B* was not effective in reducing or eliminating the micro-fissures.

In a weld made by an automatic welding machine small fissures were evenly distributed throughout. But they, too, were confined to the recrystallized area of the weld metal and were unaffected by heat treatment.

The role played by hydrogen in producing "flakes" in steel has

(Continued on page 480)



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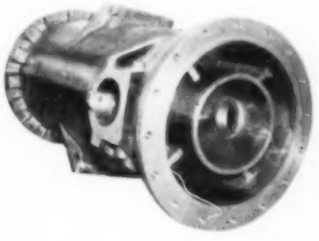

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HEAVY WELDS

(Continued from page 478)

been extensively investigated and consideration must be given to the possibility that this gas is responsible. Were hydrogen the sole or the primary cause of micro-fissuring, actual failures should be developed most readily at the lowest temperatures; they should therefore be transcrystalline, and they should be more or less indiscriminately distributed throughout the fine-grained recrystallized metal and the coarse, as-cast columnar grains.

However, all of the fissures were in the fine-grained recrystallized regions and were invariably intercrystalline, indicating that the localized failures occurred at a temperature at or above the equi-cohesive temperature, and therefore above the temperature at which hydrogen becomes insoluble in steel and hence dangerous as centers of internal pressure.

Heat treatment at temperatures ranging from 800° to 1700° F. had no effect on the size, number or distribution of the fissures present in the discontinuously welded specimens. Fissures already present cannot be eliminated by the application of heat unless the heat is accompanied by working.

The results indicate that micro-fissuring is a consequence of a combination of external and internal stresses arising from *(a)* thermal gradients between the weld metal and the cold metal of the plate proper, and *(b)* the allotropic change from austenite to ferrite occurring in material possessing reduced plasticity because of the simultaneous presence of these two phases of differing plasticity, and the presence of impurities both in solution and as inclusions. Examination of the ruptured region surrounding the fissures reveals a general condition of red shortness with many small intercrystalline failures surrounding the principal fissure. Such a condition could conceivably have been aggravated by the presence of impurities at grain boundaries. It was observed that non-metallic inclusions were sometimes associated with the micro-fissure and it is believed that they are a contributing, although not necessarily an essential, cause of fissuring.

Micro-fissuring may be minimized or eliminated by reducing the temperature difference between the plate and the recrystallizing weld metal, either by shortening the time between weld passes or by auxiliary heating of the plate material.

It is probable that plate thickness is a factor influencing the formation of micro-fissures, but no conclusive evidence was obtained.

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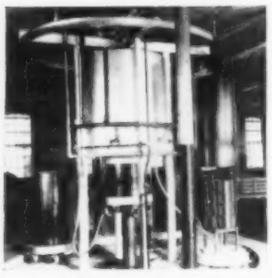

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OPENHEARTH

(Continued from page 463)

determined that $P = 215 \div T$ (Use the constant 192 if weights are expressed in gross tons.)

When values for production rates P are plotted against furnace tapping capacity in net tons (the latter to logarithmic coordinates), a straight line averages the results for modern and rebuilt furnaces, making either low carbon or medium carbon heats, and having various amounts of iron in the charge. For hot metal practice the values range as follows: $P = 26$ for a 60-ton furnace, 22 for a 100-ton furnace, 19 for a 200-ton furnace, and 14 for a 300-ton furnace.

The same type of plotting also indicates clearly the greater productive speed of the hot metal processes when compared to the cold metal process. With 150-ton furnaces the hot metal process appears to be about 25% faster; this differential appears to decrease as the furnaces become smaller.

(A corollary of the above equation is that P is equal to the number of heats made in 215 hr. operating time — not counting bottom making and between-heat delays. In other words, a 200-ton furnace on hot metal with $P = 19$ would ordinarily turn out a heat in 11 hr. and 20 min.)

Fuel — The fuels used are quite diverse, but liquid fuel predominates. For the furnaces operating on hot metal, the fuel rates vary from 2.850 million to 4.820 million B.t.u.; on all cold metal from 4.018 to 5.820 million B.t.u. per net ton of product. Six plants with furnaces working on hot metal consume less than 3.5 million B.t.u. per ton of steel over a considerable number of heats. Quite a variety of fuels are employed but the furnaces, excepting the one that has the highest fuel consumption, have shallow baths.

Twenty-five years ago fuel rates were 6 to 7 million B.t.u., ten years ago 4.5 to 5 million, and now below 3.5 million in the best practice. This indicates we are correctly applying the theory of heat transfer effects.

There are six fuels commonly used, namely, producer gas, natural gas, coke oven gas, tar, fuel oil, and refinery residues. A few plants use blast furnace gas as a part of the openhearth fuel. Nearly all are often fired in various combinations.

There are but three principal types of furnace design with respect to the fuels used: One type for producer gas firing; a second for the use of blast furnace gas, fired in combination with a richer fuel; and a third type for the richer fuels only.

These different types are due entirely to the changes in relative volumes of the products of

(Continued on page 484)

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...UCTS OF GENERAL ALLOYS MA... ...AIN OF AN INDUSTRY

GA Q'ALLOYS

GA Q'ALLOYS

GENERAL ALLOYS ENTERS A NEW PHASE

TIMES have changed," and are continuing to change, in kaleidoscopic patterns—at increasing tempo. Versatility, flexibility, ingenuity, audacity—all these, plus fatigue-resistance of a high order mark successful modern management. Of change, alone, we may be certain. Abundant life brings growth. Men outgrow organizations, and organizations outgrow men.

WHEN men are banded together by Loyalty, Mentality, and Vitality, and move with Faith and Courage, they and their works stand out amid contemporary mediocrity like a thoroughbred Dane in a dog-pound.

It's been fun piloting General Alloys, which I boarded before I could vote, often steering by bright stars then and now, invisible to others. We carried the gold of 1800 stockholders and the great names of American Industry on our manifest. Stout hearts and strong hands manned our sails, our guns, and our oars, to write the greatest log of technology and trade on the uncharted seas of new complex alloys—Engineering and Metallurgy. Even the barnacles had a good ride.

WE'VE been through a "Pioneering Phase" a "Depression and Repression Phase"—tending to standardize mediocrity—and we're at present entering a "Phase of Applied Science"—when complex alloys are just passing adolescence—when BANG! comes this new "DEFENSE PHASE"—and—NOW—GENERAL ALLOYS is—SHOOTING THE WORKS" FOR NATIONAL DEFENSE. (We've been running day and night since early in 1940)

THE immediate future will make greater demands on the Mechanical, Automotive, Metallurgical, and Process Industries than ever before in American History. Users of Mechanical Furnaces, Heat Resistant Alloys, and Corrosion Resistant Alloys in all forms will need, if they are to operate continuously at peak demand on DEFENSE PRODUCTION, not just Q-Alloys and X-ite, and the very best obtainable G. A. Alloys, but—EVEN BETTER Q-ALLOYS FOR MORE EXACTING SERVICE UNDER MORE SEVERE CONDITIONS.

ANTICIPATING these demands, General Alloys was not caught napping. To make BETTER and BETTER ALLOYS, to aid our customers in their application, we needed more competent Technical Personnel of the highest calibre in all departments of our business.

EMPHASIS has shifted from sales to MANUFACTURE, DEVELOPMENT and FIELD SERVICE. Fortunately, we have, in both metallurgical and sales engineering, outstanding Metallurgical Engineers and Metallurgists thoroughly trained in all branches of our business, who have been assigned broader responsibilities. Men we selected, from a distinguished field, men whom we believe to be best qualified to further our program of PROGRESS, DEVELOPMENT, and UNEQUALLED SERVICE TO OUR CUSTOMERS.

THESE new men, each selected for his proven ability to make substantial contributions to our organization, have joined General Alloys Corporation since September 1940. They are being integrated with our G. A. Veterans into well balanced and highly complementary combination. WE ARE NOW MANNED TO HANDLE THE "ABNORMAL" CONDITIONS OF DEFENSE PRODUCTION AS "NORMAL". OUR PERSPECTIVE WILL NOT BE LOST—OUR DEVELOPMENT PROGRAM WILL BE EXPEDITED. The "Dog" will wag the "Tail". (Three new G. A. Executives are introduced on this page, others will follow)

OUR strengthened and enlarged organization, facing an unprecedented volume of Q-Alloy and X-ite orders—will, within sixty days, be operating a greatly improved and expanded plant in which improvement of product will be accelerated ahead of production. "The footprints of General Alloys which mark the path of an industry" will now be made with "Seven League Boots"—in National Defense.

L. M. "BILL" LINDSEY
G. A. Director of Engineering Sales

ROGER D. CARVER
G. A. Superintendent

ROGER SUTTON
G. A. Director Engineering and Metallurgy

LINDSEY—4th generation. Ill. dirt farmer (like H. H. H.), graduate of University of Illinois, Mechanical Engineering, 1916. Ace Pursuit Pilot in French and American Air Service Squadrons. Pioneered Sil-O-Cel Insulating Brick in Cincinnati and Detroit territories. Engineering Sales with Holcroft & Co. in Detroit two years. Last six years with Surface Combustion Corporation, handling three Divisions—Malleable Iron Annealing, Open Flame Wire Annealing, Vitreous Enameling Furnaces, Sales and Engineering. Worked under an outstanding American Engineer, W. M. Hepburn, V. P. and Chief Engineer, Surface Combustion Corp.

CARVER—old line New Englander. Graduate of Massachusetts Institute of Technology, B.S. in Metallurgical Engineering 1922. Started as special apprentice with General Electric Lynn and Everett Works. At time of leaving in 1929 was metallurgical assistant to General Foundry Superintendent and Pattern Shop Superintendent. 1929-31 assistant works manager Symington Co., Rochester, 1931-38 Superintendent Stainless Steel and Alloys Division, Shawinigan Chemicals, Ltd., Shawinigan Falls, Que., 1938-40 Superintendent Steel Foundry, Ross Meehan Foundries, Chattanooga, Tenn.

SUTTON Native Michigander. Degree of Bachelor of Chemical Engineering, University of Detroit, 1927. Degree of Master of Science, University of Detroit, 1928. Last two years at college worked at Timken-Detroit Axle Co. in Lab. Forge Shop and heat treat. 1 year as Metallurgical and Heat Treat Superintendent with Gemmer Mfg. Co. 1 year as Chemist and Metallurgist with Forging and Casting Corporation. 1 year as Metallurgist with Holcomb Steel Co. For past 8 years Metallurgist with the Chrysler Corporation. Several years in charge of shop development work, consisting of follow up, data collection and correlation of shop and laboratory effort in all Chrysler plants and some of their larger sources of supply. Most recently Consulting Metallurgist for the Canadian plants and sources of the Chrysler Corporation. In addition was instructor of Chemistry and Metallurgy at Chrysler Institute of Engineering. Worked under F. E. McCleary, who made men and metallurgy for the Dodge Brothers—is still making them at Chrysler.

TOPS IN NEW ENGLAND CRAFTSMANSHIP PRATT & WHITNEY

THE Brains—and the guts—of the NATIONAL DEFENSE IS TOOLS.

NEW ENGLAND craftsmen are tool and alloy makers to American Industry.

WORLD tops among precision Heat Treaters are H. T. Supt. DAVE O'BRIEN and his gang at Pratt & Whitney (G. A. equipped, of course).

Q'ALLOYS

THE QUALITY NAMES IN ALLOY FOR HEAT CORROSION ABRASION

X-ite

OPENHEARTH

(Starts on page 463)

combustion inherent to the composition of the various fuels.

General Design — If the furnace has been liberally designed and constructed in accordance with our knowledge of the subject and the proper size has been selected, then the first important step has been taken.

Maintenance — After a few hundred heats, the best of furnace design and construction will avail little if maintenance and repair is not carried out on a high plane. Rebuilds must be accomplished on the premise that when a furnace is returned to production it must in all respects be as nearly in its original condition as possible.

Control of operation, whether manual, instrumental or in part both, must be on a plane commensurate with that employed in the furnace design and construction; otherwise any advantage from the installation of a good furnace may be totally lost.

If these matters concerning the furnace itself are taken care of we then have, for an integrated operation, some other things to consider, among them being

The Plant Layout — It is believed impossible to secure the maximum production from a shop unit if the shop contains more than six or seven furnaces.

Every furnace has a time constant at which it can be counted on to produce steel; extra time is often the result of platform delays of transportation, scheduling and charging, and these delays mount up with the number of furnaces in line. It has been definitely determined that, over a reasonable period of time, as great a tonnage of steel could be produced from nine to ten furnaces as could be produced when all 12 furnaces in a single shop were under heat. Six or seven-furnace operations should reduce materials handling delay nearly to zero.

Raw Material Supply — As the ratio of the iron component of the charge becomes larger, it is increasingly important that it be a product of the best blast furnace practice possible.

This means real interest and cooperation by the blast furnace operator, who incidentally has some problems of his own. Phosphorus is generally without his jurisdiction but the control of sulphur and silicon in the iron is definitely in his hands. Low sulphur should be the openhearth operator's very rigid and principal specification.

Low silicon iron should be the second principal specification. The blast furnace operator will generally hold that he cannot produce low sulphur and silicon jointly. While this idea is subject to debate, low silicon

(Continued on page 486)

ALTER EGO: Literally "one's other self"—the still, small voice that questions, inspires and corrects our conscious action.

ALTER EGO: Certainly the Whizz Electrode demonstrator showed you speed *almost* as good as with "Fleetweld."

But the speed really was good, and the weld looks OK.

ALTER EGO: Yes, but, most of all, the *demonstrator* was good. How about the *conditions* of the show?

Come to think about it—it was just a show.

ALTER EGO: Right. 'Twas the work of a good, biased demonstrator. What counts are the results of our own men—the SPEED and QUALITY *they* can attain and maintain under *production* conditions—hour after hour—day in and day out.

Well, isn't "Fleetweld" just the ticket for that? What are we waiting for?

★ ★

LINCOLN SUGGESTS: Study of welding production methods often increases speeds as much as 50% through the use of work positioning, revised technique or better types of electrodes. The "Procedure Handbook" ($1.50 postpaid) on page 210 contains valuable information on this subject. Or perhaps the Lincoln man nearby can be of service to you. No obligation, of course.

Copyright 1941, The Lincoln Electric Co.

LINCOLN "SHIELD-ARC" WELDING — THE LINCOLN ELECTRIC COMPANY, Cleveland, Ohio

Largest Manufacturers of Arc Welding Equipment in the World

Yes, THERE IS A HIGH TENSILE STEEL THAT HAS

HIGH *resistance to fatigue and impact*

AT BOTH NORMAL AND EXTREMELY LOW TEMPERATURES.

N-A-X
High Tensile

DUCTILITY
ITS INHERENTLY FINER GRAIN MAKES ALL THE DIFFERENCE
STRENGTH

PROPERTIES

TENSILE

Temperature of Test	Yield Point	Tensile Strength	Elongation in 2 Inches	Red. Area
+75°F.	53,000 P.S.I.	72,250 P.S.I.	38.8%	74.3%
−50°F.	58,000 P.S.I.	81,500 P.S.I.	37.5%	71.5%

(.505 inches diameter specimen)

CHARPY IMPACT

Temperature of Test	Foot Pounds	Specimens*
+75°F.	69	Charpy Keyhole type
−50°F.	50	Charpy Keyhole type

*Specimens were taken longitudinally to rolling direction.

The problem of finding a high tensile steel with which to build parts and mobile equipment lighter, is no longer difficult. *But getting one that has the ability to stand up under hard usage—rough roads—hard wear—constant pounding over rails at high speed—in sub-zero or extremely hot weather conditions—was a problem until N-A-X HIGH TENSILE was introduced.*

In N-A-X HIGH TENSILE you get all the advantages of a high tensile steel—*plus* unusual ductility which permits cold forming into difficult parts, in most cases without any change in shop practice—*plus* excellent resistance to impact and fatigue, not only at normal but at extremely low temperatures—*plus* exceptional weldability. As a result of these unusual properties, N-A-X HIGH TENSILE is being used successfully in scores of exacting applications where ordinary high tensile steels fail.

You will find N-A-X HIGH TENSILE well suited for any application where a superior high tensile steel is needed. A Great Lakes engineer will be glad to call, go over your high tensile steel requirements and give you advice on where you can use N-A-X HIGH TENSILE to advantage, without obligation. Telephone, telegraph or write, today. Great Lakes Steel Corporation, Detroit, Michigan.

GREAT LAKES STEEL CORPORATION——DETROIT, MICHIGAN

Boston, 460 Statler Office Building; *Buffalo,* 1000 Walbridge Building; *Chattanooga,* 18 Volunteer Building; *Chicago,* 1026 Builders Building; *Cleveland,* 820 Leader Building; *Dayton,* 1401 Third National Bank Building; *Indianapolis,* 1215-17 Circle Tower; *Minneapolis,* 714 Midland Bank Building; *New York,* 405 Lexington Avenue; *Philadelphia,* 407 Liberty Trust Building; *St. Louis,* 3615 Olive Street; *San Francisco,* 824 Sharon Building; *Toledo,* 906 Edison Building. *Montreal, Quebec,* Drummond, McCall & Co., Limited; *Toronto, Ontario,* Peckover's, Limited.

division of NATIONAL STEEL CORPORATION

Executive Offices, Pittsburgh, Pa.

(Starts on page 463)

iron is one of the greatest aids to cheap steel.

Personnel — Obviously the most carefully designed and constructed furnace, the most painstakingly laid out plant, or the finest of iron and raw materials will avail little if the operation is not conducted on the highest plane by competent and foresighted managing, purchasing, operating, inspecting and maintenance personnel, supported in the fullest degree by the correlated participating plant (blast furnace and blooming mill).

The consummation of the above is very difficult, for it means that probably at least a dozen individuals with widely assorted training and capabilities must be so imbued with the spirit of cooperation and achievement as to make an almost perfect team. This is an accomplished fact in far too few instances.

In the collection of figures already given, one plant stands out as being far above the average. Making low carbon steel in 200-ton furnaces, the value P is 26.3 instead of the "normal" or average 17. Time of heat is 8 hr. 10 min. stead of "the normal" 12 hr. 35 min. Liquid fuel is used, and consumption is 2.85 million B.t.u. per net ton steel produced, the lowest of any plant reporting. Its record for fine operation and low cost is not a sudden and unaccountable phenomenon but the result of a gradual and carefully developed and executed betterment program extending over more than ten years.

Let us "read" the records and endeavor to find to what extent this practice fulfills the optimum tenets as stated:

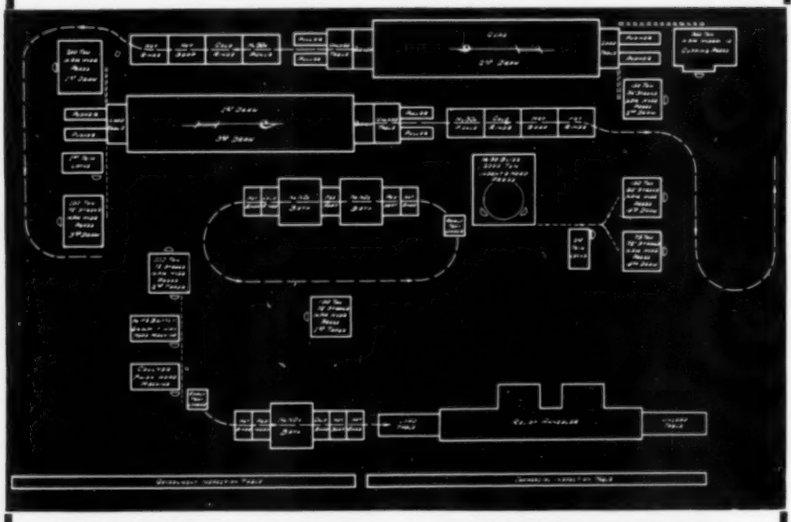
1. **The Furnaces** were constructed about 1930 and incorporate much of the design and equipment that are now considered desirable. Under the definition they are "new" furnaces, and could well be placed at 80% of ideal.

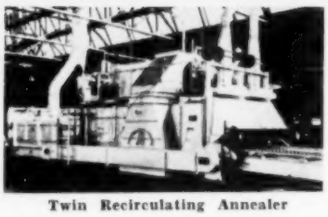
2. **The Plant** has six furnaces with ample transportation and materials handling facilities. This feature would rank nearly 100%.

3. **The Charge** — Averages 56% hot metal which contains less than 0.75% silicon and 0.04% sulphur. Purchased scrap would appear to be below the mid-west average. A 90% rating would be conservative here.

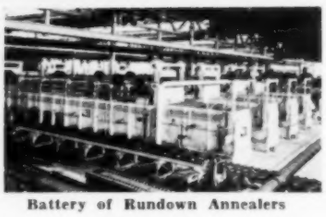
4. **The Personnel** — Based on an acquaintance with several members of the management and operating staff of this plant, the author would express the personal opinion that as individuals they are fine executives and technologists, and may be unique as a group. He has not the temerity to suggest an order of perfection in this division.

TRACING THE PATH OF A SHELL CASING





Twin Recirculating Annealer



Battery of Rundown Annealers

The journey of a shell casing through its various steps of manufacture is shown in the above layout of a plant which was engineered by CONTINENTAL.

Typical of the CONTINENTAL furnaces and equipment used in this installation are the two furnaces shown above.

The above plant layout embodies the following features for the most economical production of shell casings.

1. Straight-through flow of material.
2. No rehandling or storage is required.
3. No outside handling of containers.
4. No individual handling for pickling, salt annealing, cleaning, or stress relieving.

CONTINENTAL has engineered many such economical installations. Write, wire or telephone today for full information.

CONTINENTAL INDUSTRIAL ENGINEERS, INC.
201 N. WELLS ST., CHICAGO, ILL.

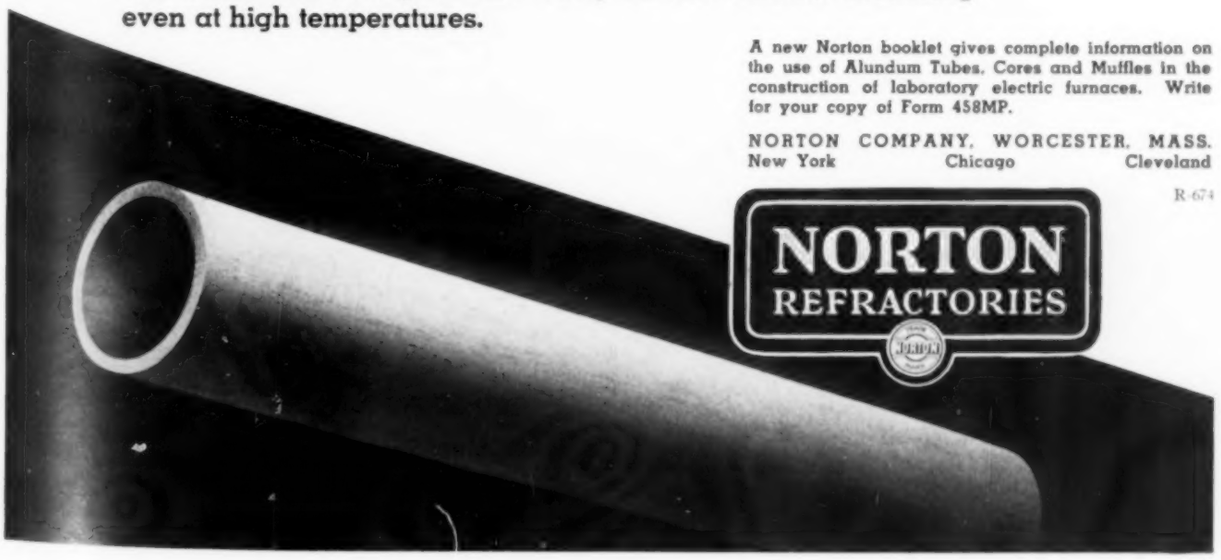
8186 Livernois Ave. Detroit | 5244 Germantown Ave. Philadelphia | 3916 Farragut Rd. Brooklyn

If You Are Building High Temperature Furnaces . . .

You'll Like the Features of ALUNDUM TUBES

BOTH in the laboratory and in commercial production, high temperature electric furnaces play an important part—furnaces which use Alundum Tubes as the working chamber.

Alundum Tubes are strong, to directly support the resistor wire, and have high resistance to abrasion to withstand the constant wear of taking work in and out. Their high permeability permits the easy maintenance of a reducing atmosphere. They have high refractoriness to resist deformation and to meet severe temperature conditions. They have high heat conductivity and low coefficient of expansion. They do not conduct electricity even at high temperatures.



A new Norton booklet gives complete information on the use of Alundum Tubes, Cores and Muffles in the construction of laboratory electric furnaces. Write for your copy of Form 458MP.

NORTON COMPANY, WORCESTER, MASS.
New York Chicago Cleveland

R-674

NORTON REFRACTORIES

FUNDAMENTALS OF NON-FERROUS ROLLING

By W. F. Chubb

(Abstracted from The Metal Industry, June 9, 1939, page 603)

Rolling may be a means of compacting a metal by closing internal cavities, a means of reducing the cross-section or reducing the metal to a definite form. Energy losses occur in friction in the roll bearings, in strain energy in the mill parts, in deforming the material being rolled, and in overcoming the slip between rolls and stock.

Numerous mathematical concepts of rolling have been developed, such as the "theory of the friction hill" with the modifications of TRINKS and HITCHCOCK and the formulas of PAVLOV and GOLOVIN. While no one of them is of itself sufficient to define accurately the conditions prevailing during any rolling operation, if viewed conjointly they provide a basis for an understanding.

Calculations of the pressure distribution show that it is the longitudinal stress which carries the material forward and not the angle of friction. The curves derived show that the total separating force is reduced by back and front tension to 25% its value when no tension is applied.

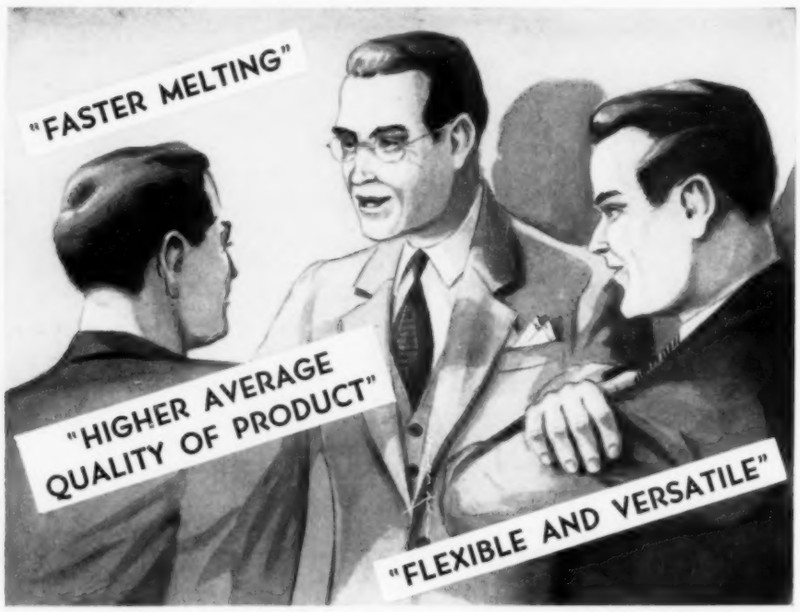
Rolling has been regarded as a wedge action leading to the conclusion that the pressure on the rolls and the gripping force on the wedge do not coincide. This conception is based upon the idea that the wedge is solid, whereas it is plastic. Nevertheless, GOLOVIN has proved that wedging action does occur.

The phenomenon of spread has also been attacked mathematically on the assumption that rolling is fundamentally a pressing operation. Other explanations of spread on the basis of pressure calculations lead logically to the existence of tensile stresses at the edges of freely spreading strip.

Because the spread is unequally distributed over the width of the material, elongation decreases from a maximum at the center to a minimum at the edge where spread is greatest.

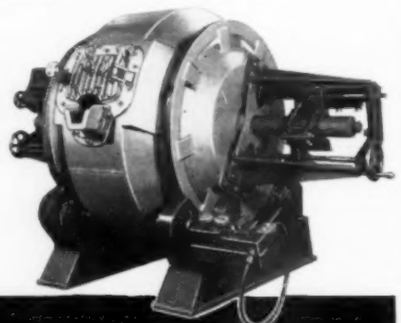
The chief influence of a lubricant is revealed in its effects upon stretching. In the case of iron, stretching may be increased up to 100%, and large increases are also obtained with copper, brass and aluminum. The composition of the oil is important.

(Continued on page 493)



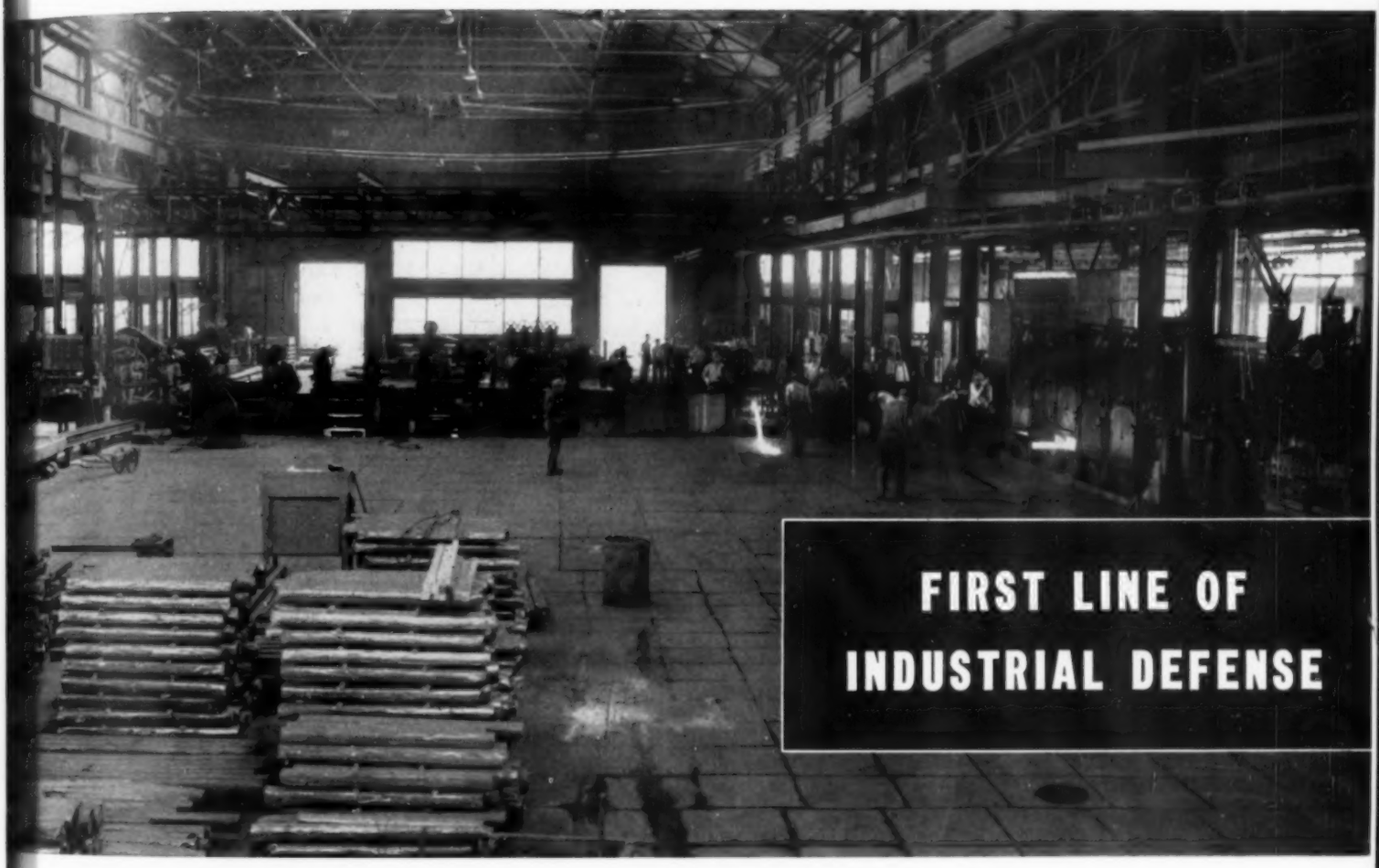
Some foundrymen like Detroit Rocking Electric Furnaces for their fast melting speed. Some like them especially for their increased yield of good castings and improvement in the average quality of the product. Some consider a Detroit Furnace's operating flexibility its most potent advantage. As a matter of fact these are only three of the many advantages you get in a Detroit Automatic Rocking Electric Furnace. Metal losses are lower. Machine shop scrap is less. Savings can be made in moulding equipment and floor space. Cheaper raw materials can frequently be used to advantage. Labor costs less.

But don't take our word for these claims — find out for yourself. Let us arrange for you to see a few of these furnaces in operation and talk to their owners yourself. Get the lowdown first hand from those who know. Write for further facts today.



DETROIT ELECTRIC FURNACE DIVISION
KUHLMAN ELECTRIC COMPANY · BAY CITY MICHIGAN

RUSTLESS



Because of the vital part that stainless steel is playing in defense activity, quality and uniformity are more important to users than ever before. In the past, these things affected profits. Now they affect the National welfare.

The Rustless plant is one of Industry's first lines of defense against production delays and rejections. Capacity has been doubled and redoubled within the last six years . . . but the product still shows the exceptional quality and uniformity that come from Rustless specialization, and that Rustless customers have learned they can always depend on.

RUSTLESS IRON AND STEEL CORPORATION
BALTIMORE, MARYLAND

RUSTLESS
STAINLESS STEEL
BARS AND WIRE

PRODUCED BY AN ORGANIZATION
MAKING NOTHING BUT STAINLESS STEEL

SALES OFFICES: BALTIMORE · BUFFALO · CHICAGO · CINCINNATI · CLEVELAND · DETROIT · LOS ANGELES · PHILADELPHIA
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NOTES ABOUT CONTRIBUTORS

FRUIT OF 32 YEARS OF RESEARCH AND experience at Cleveland Twist Drill Co. was **Joseph V. Emmons'** part in the development of the molybdenum high speed steels which apparently are destined to have an important place in national defense (see page 427). EMMONS graduated from National Normal University at Lebanon, Ohio, and did special work in chemistry at Case School of Applied Science. In 1909 metallurgy was only a small branch of chemistry, so JOE started as a chemist at Cleveland Twist Drill Co., and did not receive the title of metallurgist for quite a while. Some 20 years ago he was the chairman of the Cleveland Chapter ⊜ (then the two-year-old American Steel Treaters' Society), and in 1923 was national treasurer (then the American Society for Steel Treating). He has served as president of the Cleveland Engineering Society, and as lecturer on the metallurgy of toolsteel at Case.

⊜ ⊜ ⊜

Nathan Janco has developed several new methods of centrifugal casting, taken out patents on machines and equipment, and even made castings which some skeptical authorities claimed were impossible to cast centrifugally. He has B.S. and M.S. degrees from New York University where he taught engineering for two years. For the past six years he has been employed as a research engineer, and is now located in Tulsa, Okla. Here he organized the Centrifugal Casting Machine Co., and also has a consulting engineering practice.

James L. Foster graduated from University of Pittsburgh in 1918 as a metallurgical engineer. Since then he has been with Carnegie Steel Corp. (now Carnegie-Illinois), with Willys Overland Co. as metallurgist, and with Deere & Co. as metallurgist in the Harvester Works. At present he is metallurgist for Austin Western Road Machinery Co., Aurora, Ill., manufacturers of road machinery, dump cars, mine cars, crushers, and similar equipment.

FRANK T. SISCO

⊜ ⊜ ⊜

A southerner is **Stanley P. Watkins,** born in Alabama in 1904, in due time a student at Birmingham-Southern College. He finished his formal technical education at Carnegie Institute of Technology in Pittsburgh. He remained in Pennsylvania several years longer as associate metallurgist in the U. S. Naval Labora-

(Continued on page 492)

STANLEY P. WATKINS

Bachrach

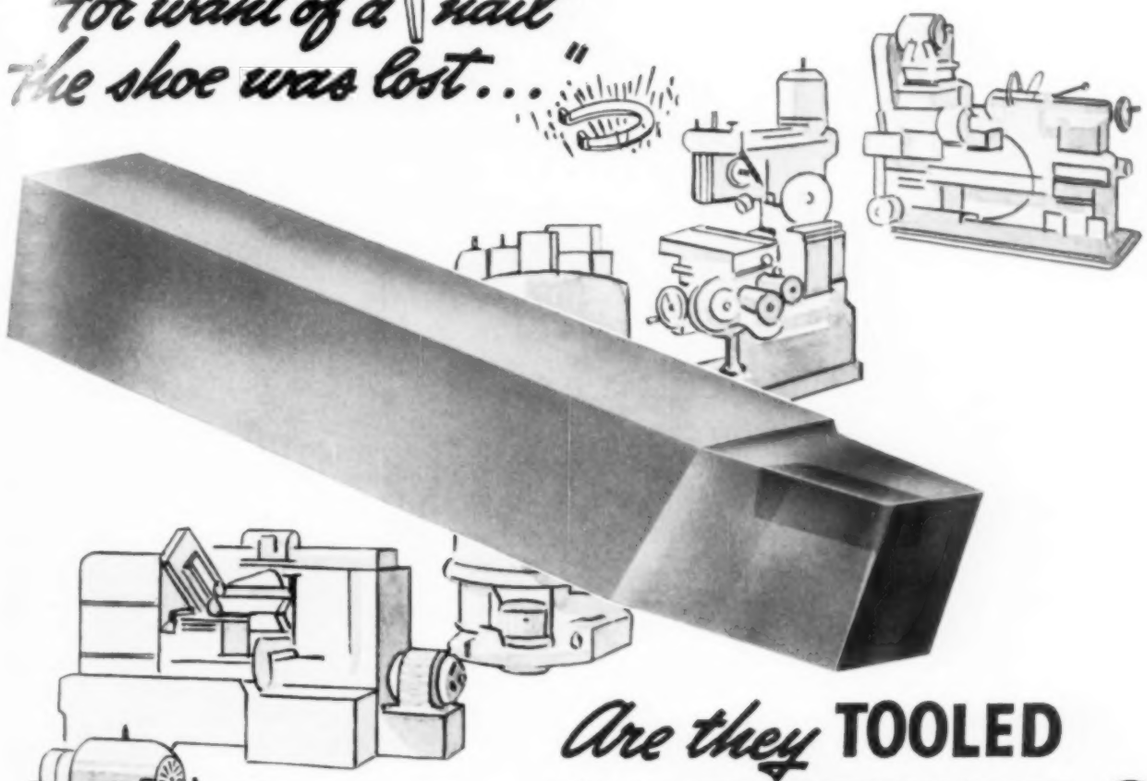
NATHAN JANCO

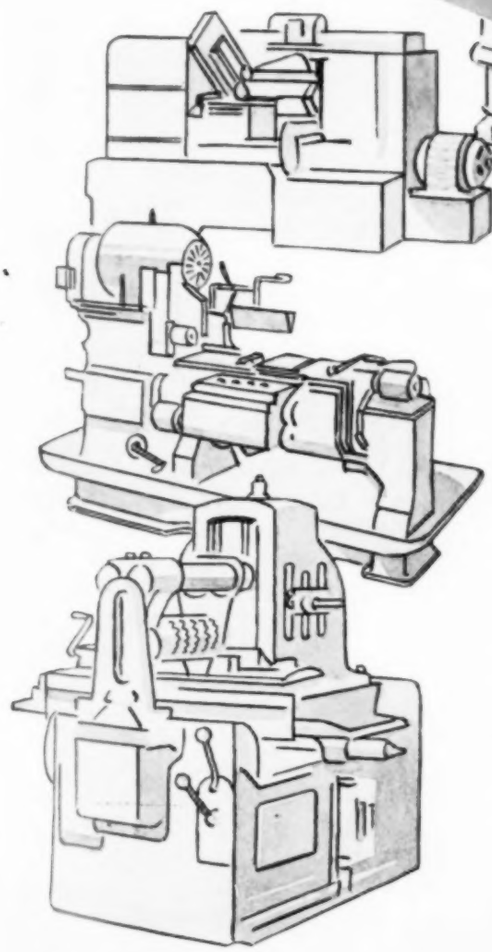
JOSEPH V. EMMONS

JAMES L. FOSTER

GORDON T. WILLIAMS

For want of a nail the shoe was lost..."





Are they TOOLED *with* FIRTHITE ?

Machine Tools are *only as productive* as the *cutting* tools and bits with which they are equipped. For want of proper Sintered Carbide tools many costly machines may be rendered ineffectual.

FIRTHITE Cutting Tools help to develop the *full-rated performance capacity* of modern machines. Hence machine tool builders will cooperate when you specify "delivery with FIRTHITE Tooling."

Thus, machine tool builders are another source of supply for FIRTHITE Sintered Carbide Tools specially adapted to their equipment. In addition FIRTHITE Tools are sold by Firth-Sterling plants, offices, and warehouses in 9 cities and through local authorized Tool Makers. Or, if you prefer, FIRTHITE Tools can be made in your own shop in four basic operations, with ordinary tool room equipment. Information about any of these optional sources, which assure you of the advantages of genuine FIRTHITE Tooling, will be furnished upon request.

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CLEVELAND DETROIT

AUTHORS

(Continued from page 490)

tory at Munhall, Pa., and as metallurgist for the Wrought Iron Research Association, Pittsburgh. In 1931 he moved to Rustless Iron and Steel Corp. in Baltimore, where he now handles the joint duties of metallurgist, sales engineer and manager of sales development.

As editor of the Alloys of Iron Research of the Engineering Foundation since its inception in 1930, **Frank T. Sisco** is largely responsible for a group of specialized technical books, as exhaustive and authoritative as is to be found. In this program more than 15 monographs which critically review and correlate the research work of the world on steels and cast irons are being published under his direction and editorship. Sisco also has four other books to his credit as author in addition to one in the monograph series on "Alloys of Iron and Carbon". One of these is "Constitution of Steel and Cast Iron" published by the ⊕ in 1930, and others treat of the analysis of steel, manufacture of electric steel, and metallurgy in aircraft. Educated at University of Illinois, FRANK was chemist for Illinois Steel Co. from 1913 to 1915; chief chemist and superintendent, Hess Steel Corp., for the next four years; chemist at the U. S. Naval Ordnance plant in 1921; and engineer of tests, American Steel & Wire Co., 1922-23. From 1923 to 1929 he was research metallurgist and chief of the metallurgical laboratory at Wright Field in Dayton. He was a national director of the ⊕ in 1929 and has been secretary and subsequently chairman of the Iron and Steel Division of the A.I.M.E.

The second in **Gordon Williams'** series of educational lectures on "Selection of Steel for Manufacturing Applications" appears on page 464. (GORDON'S biography was published in the March issue, which carried the first lecture in the series.) The course was presented before the Tri-City Chapter ⊕ during the winter (Jan. 20 to March 25), and consisted of eight lectures. Some indication of the interest it aroused may be had from the enrollment of 260 — out of a chapter membership of 140!

More practical pointers on the hardenability test are given by **Walter Jominy** this month. The first portion of this article appeared in the November 1940 issue, which also carried a brief outline of the author's career.

BEAUTY is more than skin-deep
Ferro-Carbon Titanium, used as the final deoxidizer and cleanser, improves the quality of rimming steel. Many users enthusiastically report that ingots are cleaner throughout with blow holes deeply seated. Besides, they appreciate the higher production yield that usually results with the use of Titanium. Write for full details.
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ALLOY MANUFACTURING CO.
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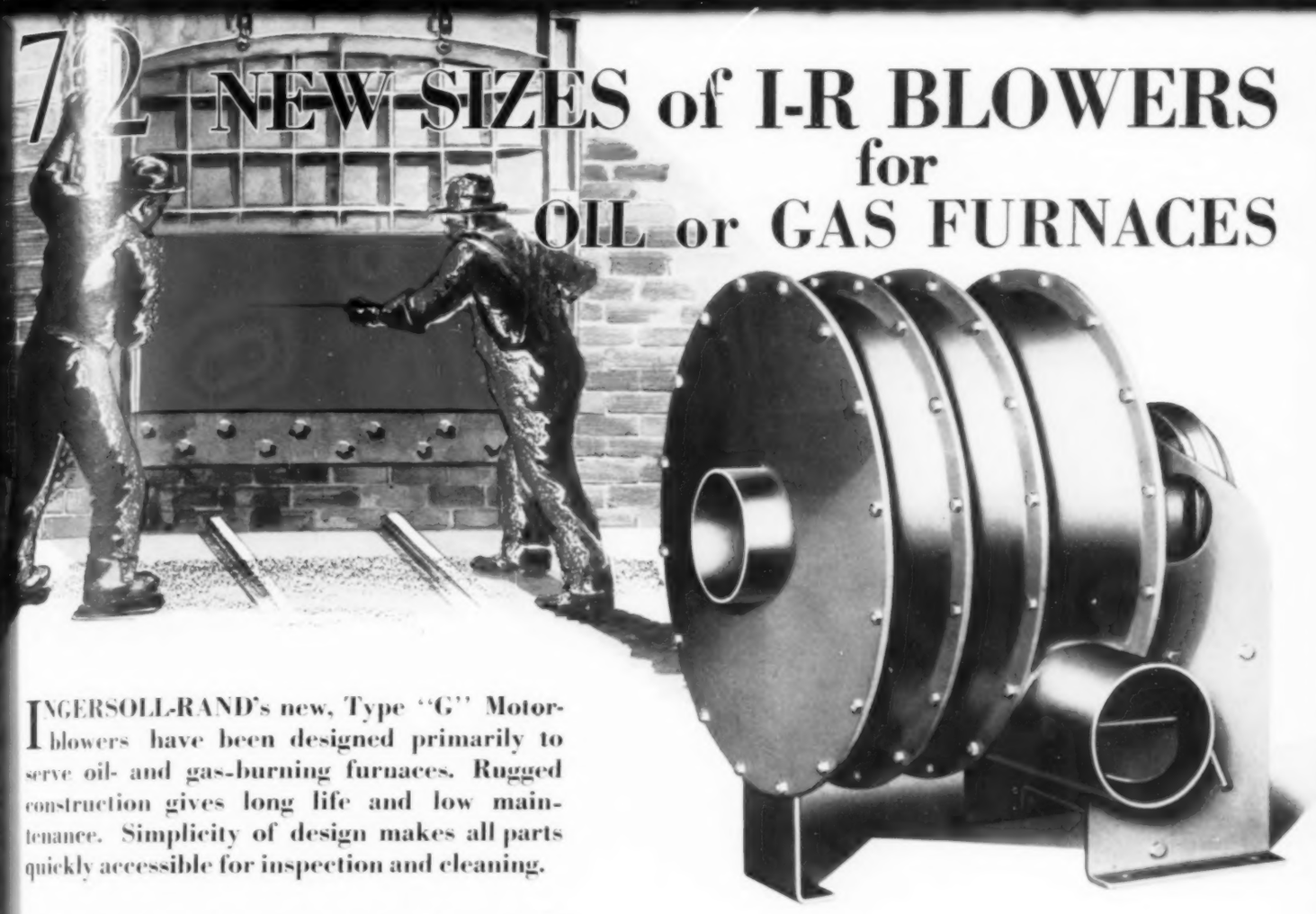
72 NEW SIZES of I-R BLOWERS for OIL or GAS FURNACES



INGERSOLL-RAND's new, Type "G" Motor-blowers have been designed primarily to serve oil- and gas-burning furnaces. Rugged construction gives long life and low maintenance. Simplicity of design makes all parts quickly accessible for inspection and cleaning.

Let us help solve your air problems. Call or write the nearest Ingersoll-Rand branch office for a demonstration. Catalog 2626 will be sent on request.

Type "G" MOTOR BLOWER

8 ounces to 2¼ lbs. pressure
100 to 4500 cfm

Important Features of Type "G" Construction

Low First Cost

There are 72 sizes from which to select—prices are attractive. Careful planning for maximum interchangeability and mass production create savings which give you a better blower for less money.

Designed For Burner Service

With the Type "G" you get full rated pressure at rated volume, and practically constant pressure throughout the entire operating range. In addition, the power consumption is almost proportionately reduced at part loads.

Quick Installation

Installation is easy. The unit can be placed wherever most convenient. Flexible pipe connector and a built-in blast gate are supplied with each unit. The gate can be locked in any desired position.

Long Life

Our shrouded impellers eliminate the necessity for close internal clearances which are expensive to maintain. Balanced rotors are carried on greased-packed ball bearings. Rolled steel casings and standard motors are used on all sizes.

The many sizes in the Type "G" line enable you to select the correct size unit for your job.

Ingersoll-Rand

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Knoxville, Los Angeles, Newark, New Orleans, New York, Philadelphia, Picher, Pittsburgh, Pottsville, Salt Lake City, San Francisco, Scranton, Seattle, St. Louis, St. Paul, Tulsa, Washington

ROLLING

(Continued from page 488)

since it has been established that the greater the fatty acid content the greater is the effect upon stretching. Straight lubricating oils are generally preferred.

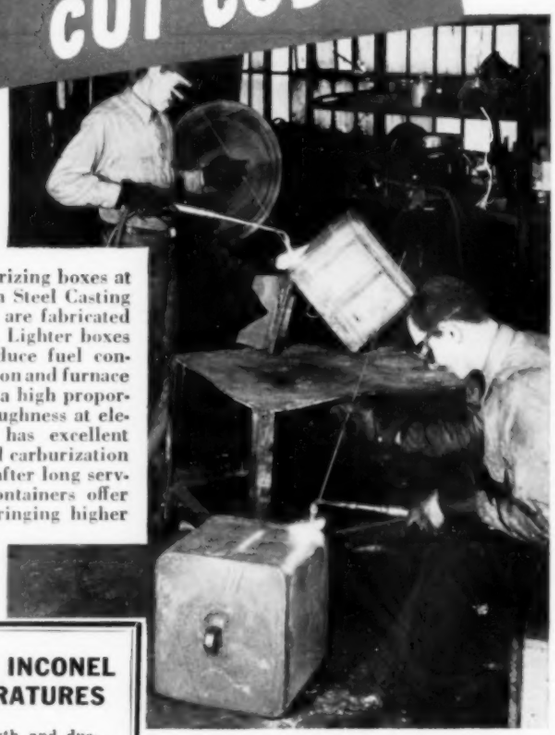
The metallurgical aspects of deformation have been considered from many viewpoints. The face-centered metals are the most easily cold worked, but do not, however, behave alike during rolling, aluminum being rather sensitive to slight differences in rolling technique, while nickel and copper are by comparison very insensitive. A small grain size results in better working qualities, this being reflected more particularly in the production of better edges. The type of melting unit, as well as the ingot molds and casting practice, thus becomes of primary importance. The electric induction furnace, in conjunction with water-cooled molds, has gone a long way toward satisfying the fundamental requirements in the copper and brass industries.

The mode of deformation may vary from simple distortion without twinning to complex twinning combined with slip. Each metal and alloy is an individual study, the mode of its deformation depending upon its initial structure, and upon the conditions of rolling.

The study of the crystallographic structures of metals and alloys thus provides a sound basis for explaining the many different behaviors exhibited during rolling. X-ray examination also shows that the diffraction pattern is weaker parallel to the direction of rolling than in a direction perpendicular to it, and the corresponding effect in the rolled metal is that rolling causes the longer dimensions of the embedded crystals to be forced into parallel alignment. The rolling texture of aluminum, copper, and nickel is related to the superposition of two crystal strata, whereas the textures of silver, brasses and bronzes are associated with only one of these strata. An ideal condition called "parallelepiped deformation" causes the texture of aluminum — that is, the mean orientation of the crystallites — progressively to become sharper with increase of pressure.

Successful cold rolling is, in a certain measure, dependent upon the proper choice of reduction and annealing sequences. The more severe the working the lower the temperature of initial recrystallization. Where the interatomic forces are sufficiently strong recrystallization takes place at ordinary temperatures, but if the rigidity of the metal is great, a large amount of additional energy as heat must be supplied and the temperature of recrystallization is much higher.

LIGHT WEIGHT INCONEL BOXES SPEED CARBURIZING, CUT COSTS..



● Welding Inconel carburizing boxes at the plant of The Michigan Steel Casting Co., Detroit. These boxes are fabricated from 1/8" Inconel* sheets. Lighter boxes transfer heat quicker, reduce fuel consumption, step up production and furnace efficiency. Inconel retains a high proportion of its strength and toughness at elevated temperatures and has excellent resistance to oxidation and carburization under high heat. Finally, after long service life, tough Inconel containers offer another cash saving by bringing higher scrap prices.

ADVANTAGES OF INCONEL AT HIGH TEMPERATURES

1. Maintains high strength and ductility.
2. Very resistant to oxidation. Oxide adherent, does not readily scale off.
3. Resistant to carburization.
4. Resistant to the effects of nitriding gases.
5. Resistant to hydrogen, cracked ammonia and other protective atmospheres.
6. Makes ductile welds, not subject to inter-granular deterioration.
7. Free from excessive distortion during sudden temperature changes, due to low coefficient of thermal expansion.
8. Readily formed into complicated shapes.
9. Mill forms and welding rod available from mill stocks.

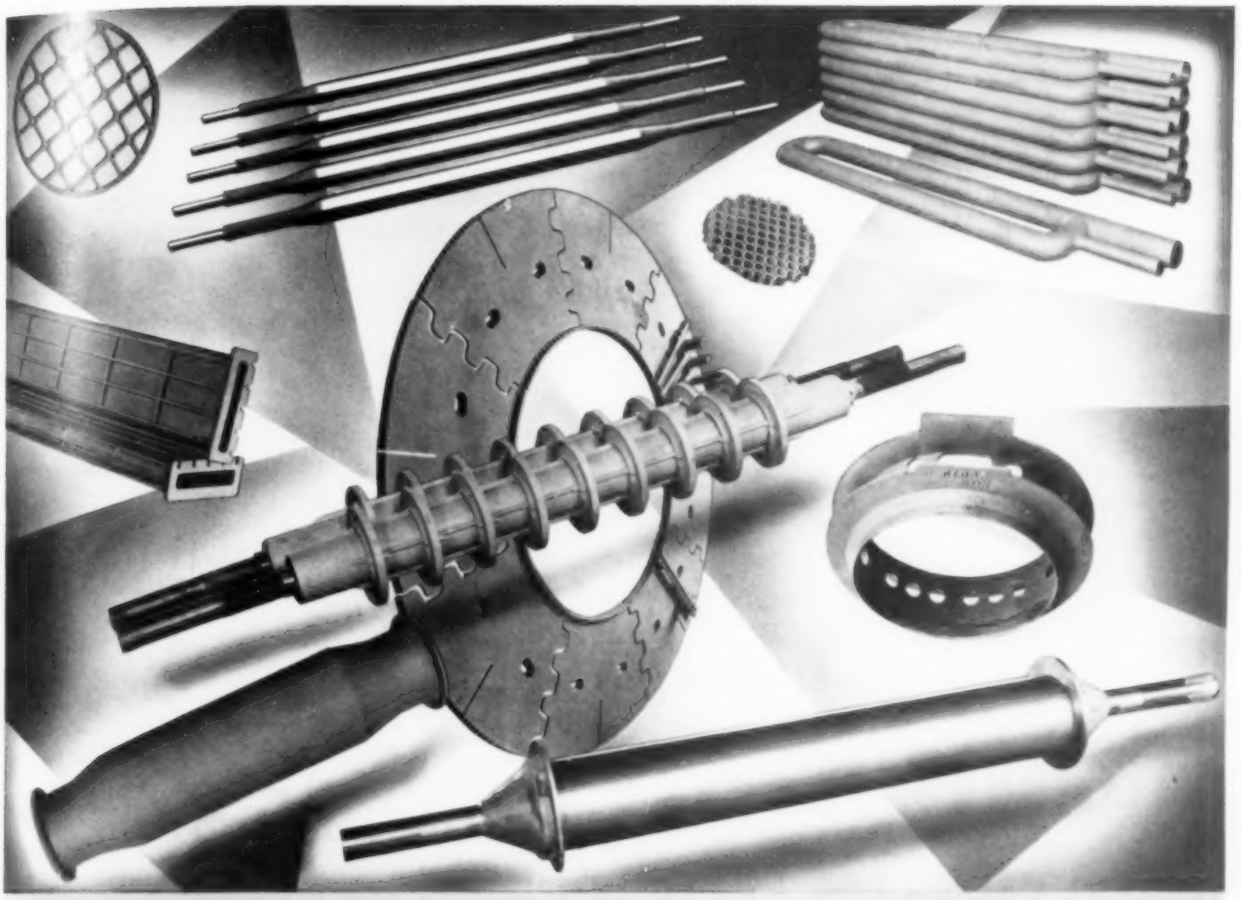
HIGH TEMPERATURE APPLICATIONS analyzed and pictured in a recently printed Bulletin C-8. For latest facts on "High Temperature Uses of Monel, Nickel and Inconel," write to:

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street New York, N. Y.

INCONEL

*"Inconel" is a registered trademark of The International Nickel Company, Inc., which is applied to a nickel alloy containing approximately 80% nickel, with additions of chromium and iron.

959-12 Pittsburgh Washington



ARMAMENT PRODUCTION DEPENDS ON MACHINE TOOLS AND GENERAL ENGINEERING EQUIPMENT

In the development of maximum properties in materials for machine tools and a host of general engineering equipment, heat treatment plays an all important part.

For the furnaces and the mechanical handling of work through these furnaces,—heat-resistant alloys are absolutely essential.

Heat-treating equipment that could stand the slower speed of the past few years is not adequate today when deliveries must be rushed.

Check over your equipment and replace the parts on which the strain of over-time falls heaviest with MICHIANA Heat-Resistant Alloy Castings for maximum heat-hours and steady production.

MICHIANA'S 23 years of specialized experience in the production of heat- and corrosion-resistant alloys is important in today's armament race... Our metallurgists and experienced organization will be glad to lend their utmost assistance. MICHIANA PRODUCTS CORPORATION, Michigan City, Indiana.

MP CORP.

MICHIANA
Heat-Resistant and Stainless Steel ALLOY CASTINGS

- Muffles
- Baskets
- Rolls
- Rings
- Retorts
- Pots
- Grids
- Tubes
- Sprockets
- Chains
- Heat-Resistant and Stainless Steel Castings of all kinds

STAINLESS

(Continued from page 458)

In another instance, in producing a screw machine part from the 17% Cr-FM grade, it was possible to make 342 pieces per hr., which was 15 higher than could be made from S.A.E. 1112 screw stock.

On the basis of the turning tests given above, 18-8 Se-FM is not as good as regular 18-8 and is considerably inferior to 18-8 S-FM. However, the type of tooling (chip curler combined with a groove) used in this test favored regular 18-8. This type of grind removes all the chips from the vicinity of the tool holder and produces a chip which is very favorable when turning regular 18-8. While the 18-8 Se-FM grade shows no advantage over regular 18-8 when cut under these conditions, it yields a more lustrous finish than the sulphur bearing 18-8. The advantage of 18-8 Se-FM over regular 18-8 lies in the ability to obtain fine finishes without the seizing characteristic of the regular grade. This feature is of importance for such operations as drilling, forming, reaming, and tapping.

Regular grades of stainless steel are difficult to grind and polish, owing to a tendency for the metal particles removed to load up the wheel and prevent proper contact between abrasive grit and metal. Sulphur and selenium impart "free-grinding" properties by minimizing this tendency. Apparently, their effect is to cause the metal particles to break free in small pieces rather than drag out in stringy particles.

Free-machining stainless steels are produced primarily in bar and wire form and find applications in practically every industry. Generally they are utilized because of their machinability, but non-seizing and free-grinding properties are important in many applications.

They are used for stems, seats and plugs in valves, machined bolts and nuts, spray nozzles, pump shafts, table knives, cable fittings, valve bodies and numerous other applications where extensive machining or grinding is involved and the service demands a corrosion resisting material. (Corrosion resistance, by the way, will be treated in a second article.) Many improvements have been made in the free-machining stainless steels since their introduction and each has been marked by their wider adoption by industry. Producers of these alloys are constantly seeking to improve their properties and machining characteristics by research and observation of their performance in service. Undoubtedly, the next decade will see further improvements in their performance arising from the correlation of laboratory and service data.

NATIONALLY KNOWN LABORATORY ASSISTANT AVAILABLE

MY experience includes work under leading metallurgists in outstanding industrial and educational laboratories. Am able to demonstrate definite savings in time and money. Have developed an exclusive method of accurately plotting continuous-line stress-strain curves simultaneously with tests.

Willing to work 24 hours a day, seven days a week if necessary, to provide you with permanent records of every tension or compression test you make in research or production control.

I am the Southwark-Templin Stress-Strain Recorder. Write or wire for Bulletin 140-B and complete information to Dept. 728, Baldwin Southwark Division, The Baldwin Locomotive Works, Philadelphia, Pa.; Pacific Coast Representative, The Pelton Water Wheel Co., San Francisco.